ISGS CONTRACT/GRANT REPORT 1985-3

STE. GENEVIEVE FAULT ZONE, Missouri and Illinois

W. John Nelson and Donald K. Lumm
Contributions by Howard R. Schwalb

Illinois State Geological Survey
Department of Energy and Natural Resources
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Nelson, W. John

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June 1985

ILLINOIS STATE GEOLOGICAL SURVEY
Natural Resources Building
615 East Peabody Drive
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ABSTRACT

The Ste. Genevieve Fault Zone crosses the northeast flank of the Ozark Dome in southeastern Missouri and extreme southern Illinois. The surface trace of faulting trends southeast and is approximately 120 miles (190 km) long. Major displacements are as much as 3,000 feet (900 m) downward to the northeast along a sharp monoclinal flexure, which is cut by one or more high-angle reverse faults. Smaller high-angle normal and reverse faults are found on both sides of the main zone. At both ends the Ste. Genevieve Fault Zone dies out into a monocline.

Two periods of faulting occurred. The first was in late middle Devonian time, and the second ran from latest Mississippian through early Pennsylvanian time, with possible minor post-Pennsylvanian movement. No evidence was found to support the idea advanced by some geologists that the Ste. Genevieve Fault Zone is part of a northwestward extension of the late Precambrian-early Cambrian Reelfoot Rift.

The Devonian faulting tilted the southwestern corner of the Sparta Shelf upward. Devonian and Silurian strata were eroded from the uplifted block; the eroded detritus was deposited in upper Middle Devonian formations south of the fault. The second episode of faulting reversed the first: the southwestern or Ozark block was uplifted. This produced an angular unconformity between Chesterian and basal Pennsylvanian strata, and apparently deflected the courses of some early Pennsylvanian rivers.

Geologic evidence and gravity data strongly favor a mechanism of vertical upthrusting of the basement, rather than horizontal compression, for the Carboniferous faulting. The master fault at depth is probably nearly vertical and penetrates the entire crust. In the sedimentary cover it becomes a reverse fault that splits and flattens upward, then passes into a flexure farther upward and at both ends.

Geologic data refute the hypothesis that a northwestern or "St. Louis arm" of the Reelfoot Rift existed as a precursor to the Ste. Genevieve Fault Zone. The magnetic and gravity anomalies cited in support of the "St. Louis arm" possibly reflect deep crustal features underlying and older than the volcanic terrane of the St. Francois Mountains (1.2 to 1.5 billion years old).

In northern Union County, Illinois, the Ste Genevieve Fault Zone apparently turns southward, splits, and gradually loses displacement. Surface faulting dies out southward, but gravity data indicate faults continue at depth, expressed as gentle folds and small faults near the surface. A southeastward extension of the fault zone across the Reelfoot Rift, as suggested by Hildenbrand et al. (1977), is unlikely.

No displacements of Quaternary sediments have been detected, but small earthquakes occur from time to time along the Ste. Genevieve Fault Zone. Many faults in the zone appear capable of slipping under the current stress regime of east-northeast to west-southwest horizontal compression. We conclude that the zone may continue to experience small earth movements, but catastrophic quakes similar to those at New Madrid in 1811-12 are unlikely.

ACKNOWLEDGMENTS

This study was carried out under a grant from the U.S. Nuclear Regulatory Commission: Grant number 1-5-24465, title NRC-04-81-016. It was part of a larger investigation involving individuals from numerous institutions, and was aimed at determining the danger of earthquakes within a radius of 200 miles (320 km) of New Madrid, Missouri, where cataclysmic earthquakes occurred in 1811 and 1812. The overall goal of the "New Madrid Study Group" was to provide background information to be used in selecting safe locations and designs for nuclear facilities around areas subject to earthquakes.

We salute Thomas C. Buschbach, Saint Louis University, skilled advisor and coordinator of the New Madrid Study Group. Peter X. Sarapuka, Illinois State Geological Survey, guided us through the paperwork and red tape that accompanies grant work.

Geologic insight and data valuable to the study were provided by Dewey H. Amos, Eastern Illinois University; George Fraunfelter and Lawrence L. Malinconico, Southern Illinois University at Carbondale; and Ira R. Satterfield, Missouri Division of Geology and Land Survey. Satterfield was especially helpful in providing subsurface data from Missouri. Stephen K. Danner, Illinois State Geological Survey, assisted in the field mapping.

Heinz H. Damberger, Richard D. Harvey, Richard H. Howard, and Howard R. Schwalb, Illinois State Geological Survey, reviewed the manuscript.

INTRODUCTION

Purpose of Study

The most earthquake-prone region in the United States east of the Rocky Mountains is the New Madrid Seismic Zone, centered along the Mississippi River at the southeastern corner of Missouri. The series of cataclysmic shocks near New Madrid in 1811-12 were among the most powerful ever recorded. Since then, many damaging quakes have shaken the surrounding region. With awareness of the danger, the public demanded that scientists determine the nature, extent, and cause of seismicity in the New Madrid Zone. In response, the U.S. Nuclear Regulatory Commission established the New Madrid Study Group, and appointed geologists, geophysicists, and seismologists from many research institutions to study all aspects of earth movements within 200 miles (320 km) of New Madrid.

One goal of the New Madrid Study Group has been to define the northernmost extent of the New Madrid Seismic Zone. Attention focused on the numerous fault systems that radiate from the head of the Mississippi Embayment through the bedrock of southern Illinois and neighboring parts of Kentucky, Indiana, and Missouri (fig. 1). The study group thoroughly investigated faults north and east of the Embayment (Kolata et al., 1981; Braile et al., 1983; Nelson and Lumm, 1984). The present investigation covers faults northwest of the head of the Embayment: the Ste. Genevieve Fault Zone and related structures.

The Ste. Genevieve Fault Zone extends from southernmost Illinois to eastern Missouri, a distance of approximately 120 miles (190 km). Bedrock along the fault zone is extensively fractured and has been displaced as much as 3,000 feet (900 m) vertically. Because several small-to-moderate earthquakes have been recorded near the Ste. Genevieve Fault Zone, some geologists have concluded that the fault zone is still seismically active (Heyl and Brock, 1965; Heyl et al., 1965). Braile et al. (1982) proposed that the Ste. Genevieve Fault Zone is related to a northwestern or "St. Louis arm" of the Reelfoot Rift, which is the forerunner of the present New Madrid Seismic Zone. Thus, the location of the Ste. Genevieve Fault Zone close to the densely populated St. Louis Metropolitan area is a matter of concern.

The goals of our study are

1. to describe the nature and extent of the Ste. Genevieve Fault Zone;

2. to determine the cause, origin, and age of the faulting;

3. to determine whether, and if so, how it is related to the New Madrid Seismic Zone; and

4. to assess the potential for earthquakes along the Ste. Genevieve Fault Zone.

As side benefits of our work, we hope to contribute to the understanding of stratigraphy, structural geology, and tectonics of the region. The

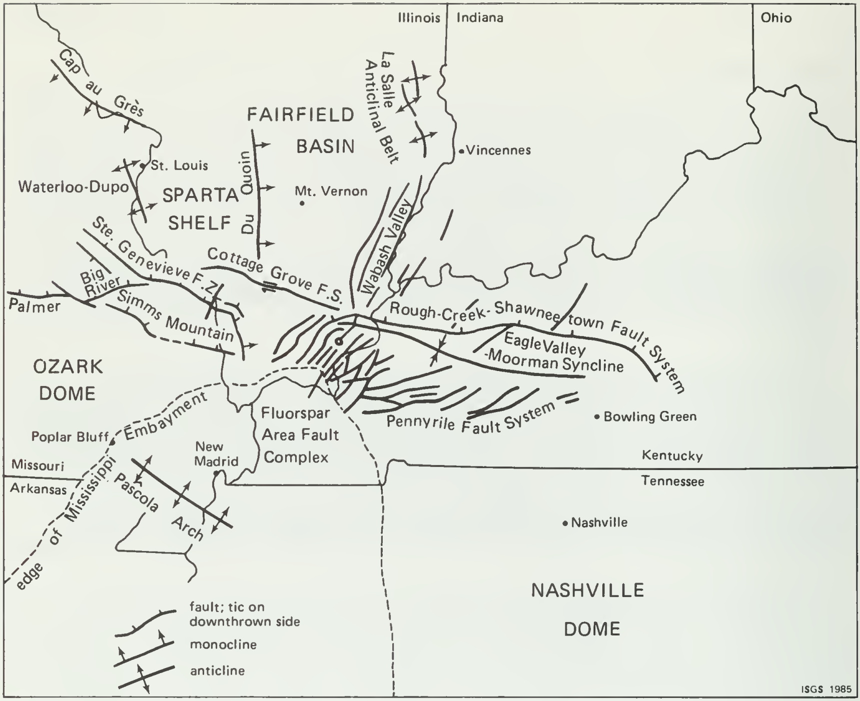


Figure 1
Regional tectonic setting of study area.

geologic data from this study will aid the search for petroleum, natural gas, and other valuable minerals.

Location and Nomenclature of Ste. Genevieve Fault Zone

Located in southeastern Missouri and extreme southwestern Illinois (fig. 2), the Ste. Genevieve Fault Zone trends northwest-southeast. Its northeast side is downthrown as much as 3,000 feet (900 m). The northeastern end is in Franklin County, Missouri, approximately 50 miles (80 km) southwest of St. Louis (McCracken, 1971). The southeastern end of major surface faulting is in Union County, Illinois (T 11 S, R 2 W); but elements of the structure continue southward into Alexander County, Illinois.

Although the faulting was recognized much earlier, the name "Ste. Genevieve Fault" apparently did not appear in print until the Tectonic Map of

the United States was published in 1944 by the American Association of Petroleum Geologists. The name is taken from Ste. Genevieve County, Missouri, where Weller and St. Clair (1928) mapped the faulting in detail. The structure has been called variously a "fault zone," a "fault system," or simply a "fault." We refer to it as a fault zone to emphasize the fact that the structure is complex, yet confined to a relatively narrow and well defined zone.

Various segments of the Ste. Genevieve Fault Zone have been given individual names (fig. 2). The northwesternmost portion has been called the Ditch Creek Fault System (Warfield, 1953). The next segment, largely in Jefferson County, is the Valles Mines-Vineland Fault Zone (Parizek, 1949). The main segment of the zone continues across Ste. Genevieve and Perry Counties, Missouri, into Jackson and Union Counties, Illinois. The largest fault in Illinois is known as the Rattlesnake Ferry Fault (Weller and Ekblaw, 1940); it coincides with a sharp monocline, which continues southward beyond the apparent termination of surface faulting. The Pomona Fault in Jackson County and many small faults between the Rattlesnake Ferry and Pomona Faults (not shown in fig. 2) are treated in this report as elements of the Ste. Genevieve Fault Zone.

Geologic Setting

The Ste. Genevieve Fault Zone lies along the northeastern flank of the Ozark Dome or Uplift, and marks in part the boundary between the uplift and the Illinois Basin (fig. 1). The Ozark Uplift has an exposed core of Precambrian igneous rocks in the St. Francois Mountains, surrounded and overlapped by sedimentary rocks dominantly of Cambrian and Ordovician age. The Illinois Basin is filled with Cambrian through Pennsylvanian sedimentary rocks, which reach a maximum thickness of approximately 15,000 feet (4.6 km). A similar but thinner, platformal sequence borders the Ozark Dome on the north and west. On the south, the Ozark Uplift and Illinois Basin are both overlapped by poorly lithified or unconsolidated Cretaceous, Tertiary, and Quaternary sediments in the Mississippi Embayment.

Several ancient structural features have no surface expression, but are primal to regional tectonic history (fig. 3). The Reelfoot Rift and Rough Creek Graben are troughs or rift zones that developed in latest Precambrian or early Cambrian time and they contain very thick early Paleozoic sediments. Both rifts have been periodically re-activated, controlling the formation of surficial faults and influencing modern seismicity. The Cottage Grove and Rough Creek-Shawneetown Fault Systems follow the northern edge of the Rough Creek Graben, while the Pennyrile Fault System of Kentucky marks the southern edge (Nelson and Lumm, 1984). Renewed movement in the Reelfoot is believed to have produced the northeast-trending fractures of the Fluorspar Area Fault Complex and Wabash Valley Fault System. All these structures date from late Paleozoic and early Mesozoic time (Nelson and Lumm, 1984). Modern earthquakes in the New Madrid Seismic Zone have been attributed to slippage on faults of the Reelfoot Rift, under the combined influence of east-west compressional stress and continued tectonic subsidence (McKeown, 1984).

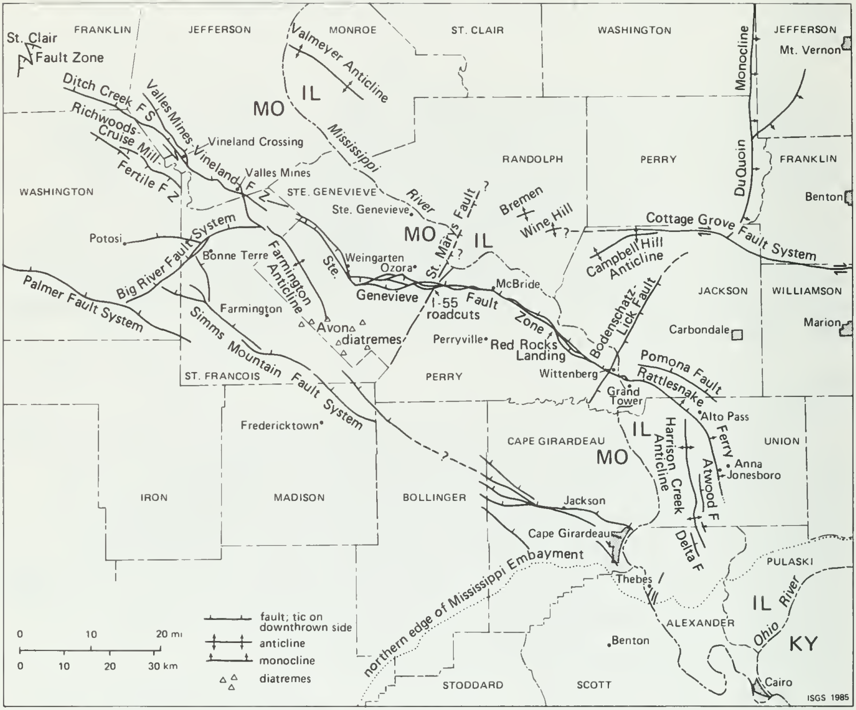


Figure 2
Ste. Genevieve Fault Zone and associated structures.

Another buried structure of considerable significance is the Pascola Arch (Grohskopf, 1955). This is a large, roughly circular, bevelled uplift of Paleozoic rocks beneath the northern Mississippi Embayment (fig. 1). The uplift and erosion probably took place in Cretaceous time (Marcher and Stearns, 1962).

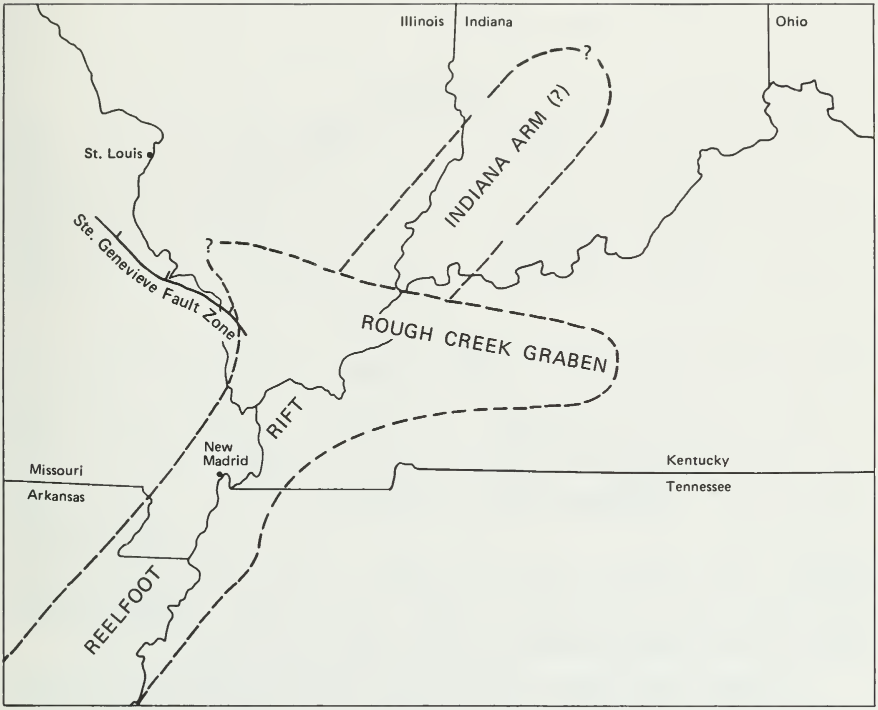


Figure 3
Rift zones or deep troughs of late Precambrian-early Cambrian age in central Mississippi Valley. Postulated "north-west arm" of Reelfoot Rift would extend to St. Louis and include Ste. Genevieve Fault Zone.

Physiography

The study area includes portions of the Interior Low Plateaus and Ozark Plateaus physiographic provinces (fig. 4). The Interior Low Plateaus Province is defined as the region south of the southern limit of glaciation and east of the uplands formed of Devonian and older rocks along the Mississippi River in Illinois (Hall, 1940). The Ozark Plateaus Province is underlain by Devonian

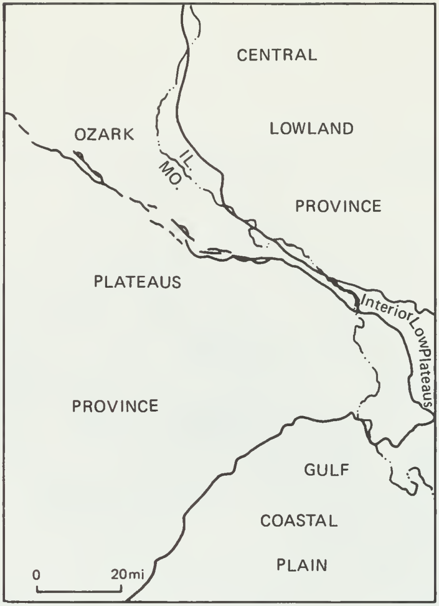


Figure 4
Physiographic provinces within the study area.

and older rocks south of the glaciated region and west of the Mississippi Embayment. The glaciated portion of southern Illinois is part of the Central Lowland Province. The Mississippi Embayment is a northward extension of the Gulf Coastal Plain, and is level to gently rolling terrain of unconsolidated and poorly consolidated Cretaceous through Quaternary sediments.

Topography in the Ozark Plateaus Province varies from gently rolling land in areas of carbonate bedrock to low mountains in the granitic Precambrian core, which is known as the St. Francois Mountains. The Illinois portion of the Ozark Plateaus Province is characterized by well dissected uplands with steep slopes and narrow, deep ravines. Stream gradients are steep, and the drainage pattern radial or dendritic. These uplands are largely underlain by thick, resistant Lower Devonian chert and siliceous limestone. The highest altitude in southwestern Illinois is 1,020 feet (311 m) on Bald Knob, Union County. Local relief is as great as 650 feet (198 m).

The Interior Low Plateaus near the Ste. Genevieve Fault Zone are underlain mainly by gently dipping Mississippian and Pennsylvanian sedimentary rocks. Relief is less (200 to 300 ft, 60 to 90 m), slopes gentler, and ravines broader in the Low Plateaus than in the Ozarks. Drainage is generally dendritic, but trellis drainage is locally developed along the Ste. Genevieve

Fault Zone, where tilted resistant and nonresistant strata form alternating hogbacks and strike valleys.

In Illinois, the Ste. Genevieve Fault Zone marks the boundary between Ozark and Interior Low Plateaus. The fault zone transects the Ozark Plateaus to the northwest in Missouri.

Climate and Land Use

The climate of southwestern Illinois and southeastern Missouri is temperate, warm, and moist. Annual precipitation is approximately 45 inches. These conditions promote deep weathering of bedrock. Outcrops are scarce except along river bluffs, in ravines, and on steep slopes where massive sandstones are present. Limestone weathers deeply by solution; areas of carbonate bedrock contain many sinkholes. Most limestone has been leached out of the Lower Devonian rocks of the uplands, leaving thick deposits of residual chert mixed with red and yellow clay. For these reasons, little useful structural information can be gained from surface exposures of the Lower Devonian rocks that border most of the Ste. Genevieve Fault Zone in Illinois.

The region is dominantly agricultural; most acreage is devoted to livestock raising and production of corn, soybeans, sorghum, winter wheat, apples, and peaches. Many farms have been abandoned and allowed to revert to brush and woodland. Large areas of southern Illinois have been included in the Shawnee National Forest. Aside from small-scale lumbering, there is little industry. Limestone, clay, and silica deposits have been quarried near the fault zone, while lead, zinc, and iron have been mined southwest of the fault zone in Missouri. Some test holes for oil and gas have been drilled in the vicinity of the fault zone, but production has been negligible and exploratory interest slight.

Previous Research

No comprehensive study of the entire Ste. Genevieve Fault Zone has been produced, but numerous geologic maps and reports cover portions of the structure. Many are out of date, out of print, or were never published. Several geologists have recently published papers attempting to fit the Ste. Genevieve into a regional tectonic framework, but their treatments of the Ste. Genevieve Zone itself are generally superficial.

The most thorough treatment of the fault zone in Missouri is found in Weller and St. Clair's (1928) report on the geology of Ste. Genevieve County, Missouri. These workers established that the zone underwent two periods of movement: the first, Devonian; the second, post-Mississippian. The earlier movement was ascribed to tensional forces, and the later faulting to compressional stress, exemplified by thrusting. Flint (1925) mapped the geology of parts of Perry and Cape Girardeau Counties, Missouri, and described faulting and related deformation in northeastern Perry county. He recognized reverse faulting and locally overturned strata, and attributed the structure to compression from the southwest.

Tikrity (1968) and Gibbons (1974) discussed the Ste. Genevieve Fault Zone in relation to regional structure of the Ozark Uplift. Both attributed the faulting to vertical uplift or tilting of basement blocks, rather than horizontal compression. Tikrity ruled out strike-slip faulting on the basis of field and subsurface evidence, and regarded vertical upthrusting as the dominant structural style of the Ozarks. Gibbons pointed out that reverse faults in the Ste. Genevieve Zone steepen rather than flatten with depth, and compared them with structures produced in laboratory experiments by Sanford (1959). In those experiments, reverse faults in near-surface layers were produced by vertical uplift of basement blocks. Like Tikrity, Gibbons found that most structures in the Ozarks conform to the upthrust model.

A concise discussion of the Ste. Genevieve Fault Zone is found in McCracken's (1971) catalogue of structural features of Missouri.

In Illinois, St. Clair (1917a) and Ekblaw (1925) presented evidence of post-Chesterian, pre-Pennsylvanian faulting along the Ste. Genevieve Fault Zone. Desborough (1961a) refined these observations in mapping and discussing the geology of the Pomona Quadrangle, Jackson County. Desborough showed that movement began after cessation of Chesterian and before commencement of early Pennsylvanian sedimentation, progressed concurrent with early Pennsylvanian deposition, and continued to some degree after early Pennsylvanian time. These findings were confirmed by Pickard (1963), Porter (1963), and Satterfield (1965) who geologically mapped quadrangles along the Ste. Genevieve Fault Zone in Jackson and Union Counties, Illinois, and discussed structural features found in these counties. The Rattlesnake Ferry Fault was described as a high-angle reverse fault; smaller faults to the northeast were described as mostly normal fractures, but little structural analysis was presented for either case. Olsson (1968), however, examined fracture patterns along the Rattlesnake Ferry Fault to explain tectonic origins. He concluded, contrary to other geologists, that the major motion was strike-slip (left-lateral) and accompanied by compressional arching of the southwestern block.

Several recent authors have attempted to place the Ste. Genevieve Fault Zone into a large regional tectonic framework. Heyl and Brock (1961), Kiilsgaard et al. (1963), and Heyl (1972) inferred strike-slip movement; whereas Viele (1983) called the Ste. Genevieve a thrust fault. These interpretations are based mainly on regional considerations and do not, to our knowledge, draw on any new findings acquired in the field.

All or part of the Ste. Genevieve Fault Zone is considered in several geophysical studies. Heigold (1976) presented an aeromagnetic map of southwestern Illinois, while McGinnis et al. (1976) mapped the gravity field of the entire state. Hildenbrand et al. (1977) mapped magnetic and gravity anomalies of the northern Mississippi Embayment and described their relationship to seismicity. Adair (1975) presented results of a series of traverses across the Ste. Genevieve Fault Zone with gravimeter and ground-based magnetometer. Most traverses were run in Missouri, but two were in Illinois. Segar (1965), who mapped gravity and magnetic fields along the eastern flank of the Ozark uplift, covered large portions of the Ste. Genevieve Fault Zone in detail.

Scope and Method of Study

Our study considers the relationships of the entire Ste. Genevieve Fault Zone to adjacent structural features, including the Ozark Uplift, the Illinois Basin, the Cottage Grove Fault System, and especially the Reelfoot Rift and New Madrid Seismic Zone. We concentrated our field efforts in Illinois, however, for the following reasons:

1. the fault zone has been studied more thoroughly and systematically, from a structural and tectonic standpoint, in Missouri than in Illinois;

2. geologists from the Missouri Division of Geology and Land Survey are concurrently mapping the fault zone in Missouri;

3. any connection of the Ste. Genevieve Fault Zone with faulting of the Reelfoot Rift would be found in Illinois.

Lacking time and resources to map the entire deformed region (practically all of Union and large portions of Jackson and Alexander Counties), we concentrated on areas where structural features appeared especially significant and/or well exposed. Surface geology was mapped at scales of 1:24,000 or more in selected areas.

Much time was spent in field-checking structures indicated on previous maps. Maps by Lamar (1925), Weller and Krey (1939), and Weller and Ekblaw (1940) are generally accurate, but lack detail and use many obsolete stratigraphic terms and concepts. Maps by Pickard (1963), Porter (1965), and Satterfield (1965) are detailed, but vary in accuracy and precision. We discovered that many mapped faults could not be verified in the field, while other structures were overlooked. Desborough's (1961a) map of the Pomona Quadrangle was most useful, although our study indicates a different interpretation of the Pomona Fault. Field interpretation is complicated by complex structure, scarcity of exposures, difficulty in recognizing stratigraphic units, and widespread occurrence of landslide and karst features.

Subsurface information was used wherever available; however, borings adjacent to the fault zone are widely scattered, and the quality of the logs is poor to unusable. We checked all available well records on file at the offices of the Illinois State Geological Survey and the Missouri Division of Geology and Land Survey. These logs cannot be used for detailed structural mapping, but do provide much valuable stratigraphic information, and give the only data on structure for large areas covered by glacial drift or alluvial sediments.

In conjunction with this study, Mitchell Coe from Southern Illinois University ran a series of gravity profiles across the Ste. Genevieve Fault Zone in Illinois. Coe and his faculty advisor, Lawrence L. Malinconico, reduced the data. Results of this work are presented in the section on geophysics.

STRATIGRAPHY

Precambrian rocks

Precambrian rocks crop out extensively in the St. Francois Mountains of southeastern Missouri, and have been encountered in a number of deep boreholes in Illinois. Although no drill has yet reached basement in the northern Mississippi Embayment, some inferences on Precambrian geology in this area can be drawn from geophysical data.

The most comprehensive study of Precambrian geology in the St. Francois terrane is that of Kisvarsanyi (1981). This investigation integrates outcrop and recent borehole data with petrographic, geochemical, and aeromagnetic data; it provides the first true historical synthesis of Precambrian geology in Missouri. The oldest rocks are rhyolitic lava flows, ash-flow tuffs, and minor bedded tuffs, along with very local stromatolitic limestone (Stinchcomb, 1976) and underlying granophyric biotite granite. The extrusive rocks represent the root zone of a volcanic complex with an eroded superstructure; granite is the subvolcanic massif. Partial emptying of the magma chamber led to cauldron subsidence and emplacement of granite, syenite, and granitic porphyry as a series of large ring intrusions. Believed to be of similar age as the rings are bodies of intrusive and extrusive trachytes and trachybasalts. After formation of the ring intrusions, new magma welled up in the underlying central chambers. This magma cooled and hardened as a two-mica, microcline and albite granite. Finally, all these rocks were invaded by small dikes and sills of olivine diabase.

Radiometric ages of rocks from the St. Francois Mountains are somewhat discordant. Muehlberger et al. (1966) gave Rb-Sr dates of 1260 to 1330 million years on rhyolites and 1200 to 1250 million years on granites in the Ozarks. Bickford (1976) reported Rb-Sr ages of 1273 to 1408 million years, but his U-Pb ages from zircons in the same rocks fell mainly in the range of 1500 to 1530 million years. Bickford considers the U-Pb determinations more reliable and speculates that Rb-Sr ages were lowered by the loss of strontium from the rocks after crystallization. Isotopic ages of specific rocks do not necessarily agree with the relative ages as outlined by Kisvarsanyi (1981). The diabase intrusions have not been dated isotopically because they lack the requisite minerals. Therefore, they are known only to be younger than other Precambrian rocks and older than the Upper Cambrian Lamotte Sandstone, which overlies diabase unconformably.

Igneous rocks of the St. Francois terrane must rest upon an older, unexposed "basement." The nature of this substrate is indicated by xenoliths of schist and gneiss in a diatreme located about 6 miles northeast of Farmington, Missouri (Tarr and Keller, 1933). Metasediments, along with gneissic granite and intermediate to basic igneous material, also have been recovered from wells in western and north-central Missouri. Hayes (1961) believed the floor complex of the St. Francois Mountains to be composed of such rocks.

In Illinois, the Precambrian basement is known only from about 20 deep oil-test holes. All have encountered granite, rhyolite, and related rocks similar to those exposed in the St. Francois Mountains.

The deep crustal structure of the Mississippi Embayment has been interpreted from reflective and refractive seismic profiles, earthquake data, and gravity and magnetic surveys. Ervin and McGinnis (1975) established the presence of the Reelfoot Rift (fig. 3), a deep linear trough in the basement beneath the Embayment. They proposed that this feature originated approximately 1.2 billion years ago when upwelling in the mantle arched and fractured the overlying crust. The diabasic intrusions in the Ozarks are supposed to have been emplaced during this initial rifting. According to Ervin and McGinnis (1975) isostatic subsidence of the rift produced a trough that filled with Cambrian sediments. (Cambrian and later history of the Reelfoot Rift will be discussed in upcoming sections of this report.)

Subsequent gravitational and magnetic surveys have led to refined interpretations of the rift zone. Aeromagnetic mapping by Hildenbrand et al. (1977 and 1982) suggests that the graben is 5,000 to 9,000 feet (1,500 to 2,700 m) deep. Seismic refraction and gravity surveys by Mooney et al. (1983) and Ginzburg et al. (1983) show a zone of low density rock below Paleozoic carbonates along the axis of the rift. This zone, which is up to about 10,000 feet (3,000 m) thick, is believed to consist of Precambrian and/or early Paleozoic clastic sedimentary rocks. Small but intense magnetic highs between the Reelfoot Rift and exposed St. Francois terrane are thought to indicate mafic intrusions in granitic country rock. The magnetic pattern of basement southeast of the rift differs markedly from that northwest of the rift. This fact, plus limited drillhole information from Tennessee, led Hildenbrand et al. (1982) to suggest that basement southeast of the rift belongs to the Grenville Province--metasediments 1.0 to 1.1 billion years old. They further speculate that the rift developed along the boundary dividing Grenvillian rocks from the older granitic rocks of the St. Francois terrane.

Seismic reflection profiles, recently supplied by oil companies, indicate 1,500 to 3,000 feet (450 to 900 m) of layered rocks below magnetic basement in the Reelfoot Rift. McKeown (1984) theorizes that the layered material is felsitic volcanic rock, which may be either comparable to that in the Ozarks, or younger material extruded during rifting. The profiles also show the rift boundaries as wide fracture zones and suggest the presence of mafic plutons. Plutons along the rift margins are strongly indicated by magnetic data, but are believed to be of Mesozoic age (Hildenbrand et al., 1982).

Cambrian System

• Pre-Lamotte rocks

The oldest Paleozoic sediments in the area of interest are marine clastics and carbonates of middle and early (?) Cambrian age, underlying the Lamotte Sandstone within the Reelfoot Rift and Rough Creek Graben. The presence of these rocks is known from deep wells and reflection seismic profiles. Coarse red arkosic sandstone found below the Lamotte in a well in Johnson County, Illinois, has been informally termed "Mermet Sandstone" (Schwalb, 1982). This apparently grades southward to basinal shale and is overlain by more than 1,000 feet (300 m) of dolomite (?) farther south in the Mississippi Embayment (Houseknecht and Weaverling, 1983). No wells have yet

penetrated these strata to basement; but seismic data suggest as much as 10,000 feet (3,000 m) of clastic sediments (Mooney et al., 1983; Ginzburg et al., 1983). The distribution of pre-Lamotte rocks clearly reflects foundering of the rift valleys at the start of the Paleozoic, when surrounding areas still stood above the sea.

• Lamotte or Mt. Simon Sandstone

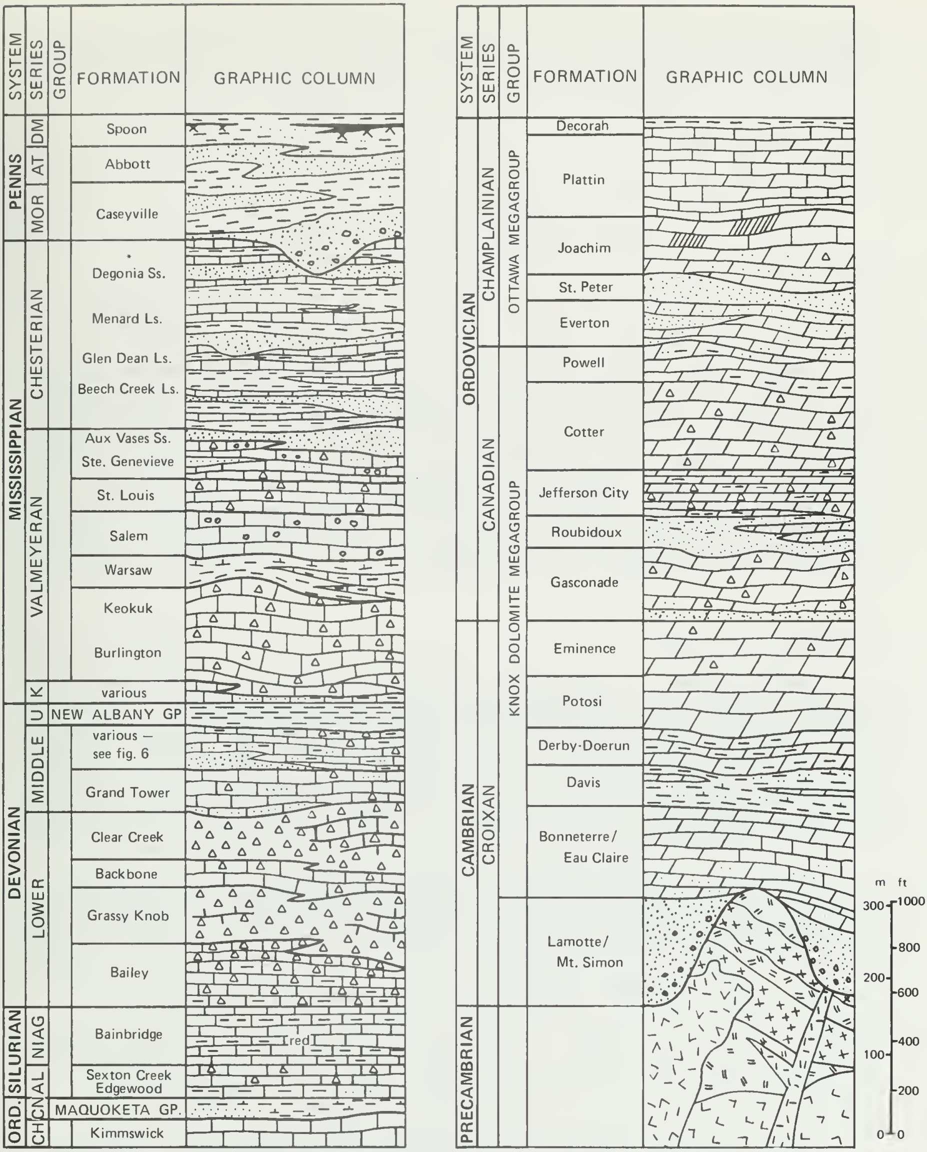
The basal transgressive Cambrian sandstone outside of the rifts is called the Lamotte Sandstone in Missouri and the Mt. Simon Sandstone in Illinois (fig. 5). It is considered to be entirely Upper Cambrian, although conclusive evidence is lacking (Willman et al., 1975). Away from rifts, the Lamotte/Mt. Simon was deposited upon an irregular Precambrian surface marked by many hills or knobs with up to 1,000 feet (300 m) of relief. The sandstone failed to cover the higher hills and there is overlapping of younger formations. The Lamotte in the Ozarks is up to 500 feet (150 m) thick and quartzose to arkosic, with beds of conglomerate near the base containing pebbles of local igneous rocks (Hayes and Knight, 1961). A major center of deposition was in northeastern Illinois, where the Mt. Simon reaches its maximum thickness of about 2,600 feet (790 m) (Willman et al., 1975). The unit also thickens to several thousand feet into the Reelfoot and Rough Creek troughs, and it grades laterally into basinal shales with interbedded coarse sandstones that may represent submarine fans (Houseknecht and Weaverling, 1983). The rifts contained deep marine water and probably were still subsiding as the Lamotte/Mt. Simon was being deposited.

• Bonneterre or Eau Claire Formations

The Bonneterre (Missouri) or Eau Claire (Illinois) Formation is dominantly sandy dolomite, limestone, and dolomitic sandstone away from the Reelfoot Rift and Rough Creek Graben. This formation conformably overlies the Lamotte/Mt. Simon except over Precambrian hills where the sandstone is missing. The center of deposition had shifted from northeastern to southeastern Illinois, with the thickest sedimentation being in the grabens. Continued sinking of the rifts is indicated by marked thickening of the Bonneterre/Eau Claire and lateral gradation from shallow-water carbonates on the shelves to dark shale in the rifts (Schwalb, 1982; Houseknecht and Weaverling, 1983).

• Younger Cambrian Formations

Together with Ordovician rocks below the St. Peter Sandstone, Upper Cambrian rocks of the Illinois Basin constitute the Knox Dolomite Megagroup. The Cambrian portion of the Knox Dolomite Megagroup is subdivided into (from oldest to youngest) the Davis Shale and Derby-Doerun Formations (Missouri) or Franconia Formation (Illinois), the Potosi Dolomite, and the Eminence Formation. The latter two are mainly dolomite, while the former contain shale, siltstone, sandstone, limestone-conglomerate, and dolomite. The Cambrian portion of the Knox thickens from approximately 1,000 feet (300 m) along the Ste. Genevieve Fault Zone to 4,000 feet (1,200 m) in the Reelfoot Rift.



*only selected Chesterian formations are identified

series abbreviations:

Al — Alexandrian	Cn — Cincinnatian	Mor — Morrowan
At — Atokan	Dm — Desmoinesian	Niag — Niagaran
Ch — Champlainian	K — Kinderhookian	U — Upper Devonian

ISGS 1985

Figure 5
Generalized stratigraphic section along Ste. Genevieve Fault Zone.

The influence of Reelfoot Rift and Rough Creek Graben was waning in late Cambrian time; thickening of Knox strata into the troughs is less pronounced than in older units, and the change in facies is slight (Schwalb, 1982).

Ordovician System

• Canadian Series

The Canadian Series, which contains the Ordovician portion of the Knox Megagroup, is also known in Illinois as the Prairie du Chien Group. Sandy and cherty dolomite, along with quartzose, dolomitic sandstone, make up this interval. The oldest Ordovician formation in the Ozark region is the Gasconade Dolomite, which has the Gunter Sandstone Member at the base. The contact with the underlying Cambrian Eminence Formation apparently is conformable. Above the Gasconade is the Roubidoux Sandstone, reddish brown, locally shaly, and dolomitic. This is overlain in turn by the thin-bedded, cherty Jefferson City Dolomite, the thicker bedded Cotter Dolomite, and the shaly, sandy Powell Dolomite. Aggregate thickness of these units is roughly 1,000 feet (300 m). This thickens to more than 2,600 feet (790 m) in the southern Illinois Basin, where the succession is similar but different formational names are used. In the northern Mississippi Embayment, up to 3,500 feet (1,070 m.) of Canadian strata have been recognized, a fact which indicates that subsidence of the Reelfoot and Rough Creek Grabens continued, although at a slower pace than in Cambrian time.

• Champlainian Series

Everton Dolomite. The oldest Champlainian unit in the study area is the Everton Dolomite, a gray sandy dolomite with lenses of dolomitic sandstone. The sand is well rounded frosted quartz, similar to that in the overlying St. Peter Sandstone. The Everton is up to 500 feet (150 m) thick in southeastern Missouri and southern Illinois, but it rapidly thins northward. It does not thicken appreciably into the Rough Creek Graben and Reelfoot Rift. Subsidence and filling of these troughs apparently was more or less complete by the time of Everton deposition.

The Everton is bounded by unconformities above and below. The upper unconformity beneath the St. Peter is much more widespread regionally than the lower unconformity. In the study area, however, the lower unconformity is more pronounced than the upper.

St. Peter Sandstone. The St. Peter Sandstone is a very extensive and distinctive formation composed of very clean, white, well sorted, well rounded, frosted quartz sand. It is 50 to 100 feet (15 to 30 m) thick along the Ste. Genevieve Fault Zone, but reaches 500 feet (150 m) thick only 25 miles (40 km) northeast of the fault zone in Illinois. The St. Peter is considered a shallow marine, transgressive sandstone.

Ottawa Limestone Megagroup. Champlainian rocks above the St. Peter Sandstone are assigned to the Ottawa Megagroup. These are mainly limestones

and some dolomite, chert, and shale deposited in a broad basin centered south of Illinois (Willman et al., 1975). In Missouri, the light gray, siliceous Joachim Dolomite is the lowest formation in most places along the fault zone, although the dark gray, dolomitic Dutchtown Limestone is present beneath the Joachim in southernmost Missouri. The Joachim is overlain by the fine-grained Plattin Limestone which in turn is overlain by the thin Decorah Shale. At the top of the Ottawa Megagroup is the very pure, white, crystalline Kimmswick Limestone. The total thickness of the megagroup is roughly 1,000 feet (300 m). In Illinois, the Platteville Group equals the Plattin of Missouri; whereas the Galena Group equals the Decorah and Kimmswick.

• Cincinnatian Series

Maquoketa Shale Group. Abundant clay and silt, derived from lands uplifted by the Taconian Orogeny in the northeastern United States were carried into the Illinois Basin during Cincinnatian time. The resulting silty, calcareous, or dolomitic shales and thin-bedded argillaceous carbonates make up the Maquoketa Shale Group in Illinois and Missouri. Total thickness of the group varies from 30 to 150 feet (15 to 45 m) along the Ste. Genevieve Fault Zone. A fine-grained silty sandstone, the Thebes, is present in the Maquoketa of extreme southwestern Illinois and southeastern Missouri. The derivation of this sand apparently has not been studied. Its restriction to the flanks of the Ozarks suggests a local source and, possibly, local uplift in southeastern Missouri.

Silurian System

Silurian rocks in the study area are approximately 200 to 300 (60 to 90 m) thick. Initial deposits of the Alexandrian series unconformably overlie the Maquoketa Shale Group and consist of slightly silty and cherty limestone and dolomite; these are of shallow-water origin. Niagaran time saw the development of a deep marine basin centered in extreme southern Illinois and termed by Rogers (1972) the "Metropolis Depression." Characteristic red-pink silty or argillaceous limestone and calcareous siltstone accumulated in the depression, while pinnacle reefs grew along the subsiding margins. The main belt of reefs extends from Randolph County, Illinois, northeastward into Indiana and beyond. Sedimentation probably continued without a break through Cayugan time into Devonian time within the Metropolis Depression. Cayugan deposits in the Illinois Basin include greenish gray calcareous shale and siltstone, grading upward into the Bailey Limestone, which probably contains the Silurian-Devonian boundary in its lower portion (Rogers, 1972).

Devonian System

• Lower Devonian Series

The Metropolis Depression persisted throughout early Devonian time and accumulated more than 1,000 feet (300 m) of sediments in its deepest portion. The oldest formation in the depression is the Bailey Limestone. This silty, argillaceous, cherty fine-grained limestone is characterized by

thin, very regular, graded beds. On the basis of a microfacies study, Banaee (1981) interpreted the Bailey as turbidites deposited in a series of coalescing submarine fans within the basin. The large quantities of silt, mud, and fine sand in the Bailey may have been derived from the Cincinnati Arch (Rogers, 1972) or from a partially exposed shelf surrounding the basin to the north and west (Banaee, 1981). Much of this silica was altered to chert during early diagenesis (Banaee, 1981).

Above the Bailey, thick chert/limestone formations in the deep basin intertongue with pure crystalline bioclastic limestones on the shelf margins. The edge of the shelf runs approximately from Perry County, Missouri, northward to Bond and Fayette Counties, Illinois, and then eastward. The basinal Grassy Knob (older) and Clear Creek Cherts consist of bedded chert interlayered with limestone that is less silty and argillaceous than that of the Bailey. Grassy Knob limestone is dominantly fine grained and nonfossiliferous; Clear Creek limestone is coarser, more crystalline, and quite fossiliferous. Shelf-margin limestones include the Ozora Limestone of Rogers (1972), between the Bailey and the Grassy Knob; and the Backbone (Illinois) or Little Saline (Missouri) Limestone between the Grassy Knob and the Clear Creek. The limestone accumulated in shallow, well agitated water where life was abundant; whereas the basinal cherts were derived from detrital and bioclastic material swept off the slopes and possibly mixed with chemical precipitates. Detailed environmental analysis of the Grassy Knob and Clear Creek Formations is difficult because the limestone has been leached out of most surface exposures, leaving only residual chert.

Toward the end of early Devonian time the seas largely withdrew from the Illinois Basin, and the sediments were eroded. The resulting regional unconformity separates the Tippecanoe Sequence below from the Kaskaskia Sequence above (Sloss et al., 1949). In former shelf areas, Middle Devonian rocks rest directly on Silurian or older strata. Progressively less erosion took place to the south and east. Middle Devonian rocks lie conformably on Lower Devonian near the center of the former Metropolis Depression.

• Middle Devonian Series

The earliest known tectonic movements on the Ste. Genevieve Fault Zone took place in late Middle Devonian time. Evidence for this activity is largely stratigraphic; the Devonian faults are largely hidden by younger sediments. Middle Devonian stratigraphy, therefore, is discussed in more detail than the stratigraphy of older rocks.

Weller and St. Clair (1928) found the most direct evidence of Middle Devonian tectonism in the vicinity of Ozora in Ste. Genevieve County, Missouri. In this area, the fault zone is complex--more than 2 miles wide in places--and outlines (in map view) a series of diamond-shaped slices. South of the fault zone, Ordovician and older rocks are at the surface, while within the slices a complete section of Ordovician, Silurian, and Lower and Middle Devonian strata is occurs. North of the zone, however, basal Mississippian rocks rest directly on Silurian strata or Maquoketa Shale. The area north of the fault zone thus was uplifted, and Devonian strata eroded before the Mississippian sediments were deposited.

The same relationships are confirmed by drilling along the fault zone east of Ozora. The well data indicate a "hinged" movement, with uplift greatest to the west and diminishing eastward into Illinois. In Ste. Genevieve County, most borings north of the fault zone find Mississippian rocks in contact with Ordovician or lowest Silurian strata. More of the Silurian is preserved eastward in Perry County (Missouri); and some logs show a thin black Upper Devonian shale below the Mississippian, indicating that sedimentation had resumed on the upthrown fault block by late Devonian time. Upper Devonian shale overlies Lower Devonian chert in Jackson County, Illinois. Farther east and south, the complete Devonian section is present.

West of Ozora, only Ordovician and older rocks are preserved, so the extent of Devonian faulting cannot be determined.

Middle Devonian rocks exposed in the fault slices and southwest of the fault zone contain additional evidence on the nature and timing of uplift.

Grand Tower Limestone. The oldest Middle Devonian formation in the study area is the Grand Tower Limestone (fig. 6). The thickness and distribution of the Grand Tower are shown in figure 7. The limestone is thickest along the trend of the Rough Creek Graben in southeastern Illinois and western Kentucky. Renewed subsidence of the graben may have been responsible for this thickening. The Grand Tower was not deposited on the Sparta Shelf (Meents and Swann, 1965; North, 1969a). The shelf evidently was a positive area, perhaps undergoing the first stages of uplift, as Grand Tower Limestone was accumulating.

A narrow belt of Grand Tower crops out within and immediately south of the Ste. Genevieve Fault Zone and extends from Union County, Illinois westward to Ozora in Ste. Genevieve County, Missouri. The Grand Tower is thicker in this belt--up to 160 feet (49 m)--than elsewhere in southwestern Illinois. Meents and Swann (1965) supposed that this limestone was deposited in a narrow

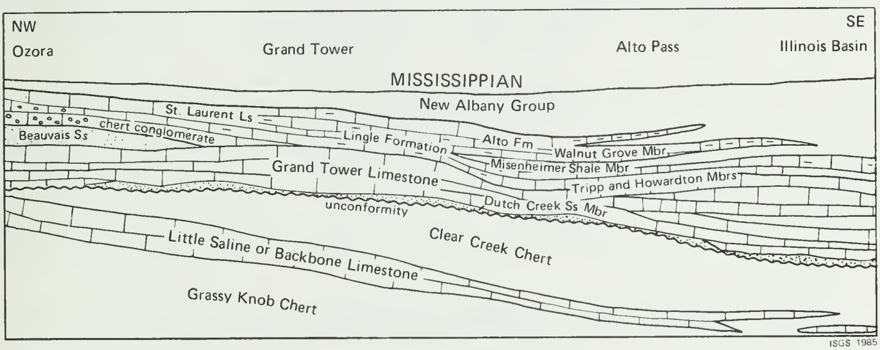


Figure 6
Interpretive cross section of Devonian strata from Ozora, Missouri, to southeastern Illinois.

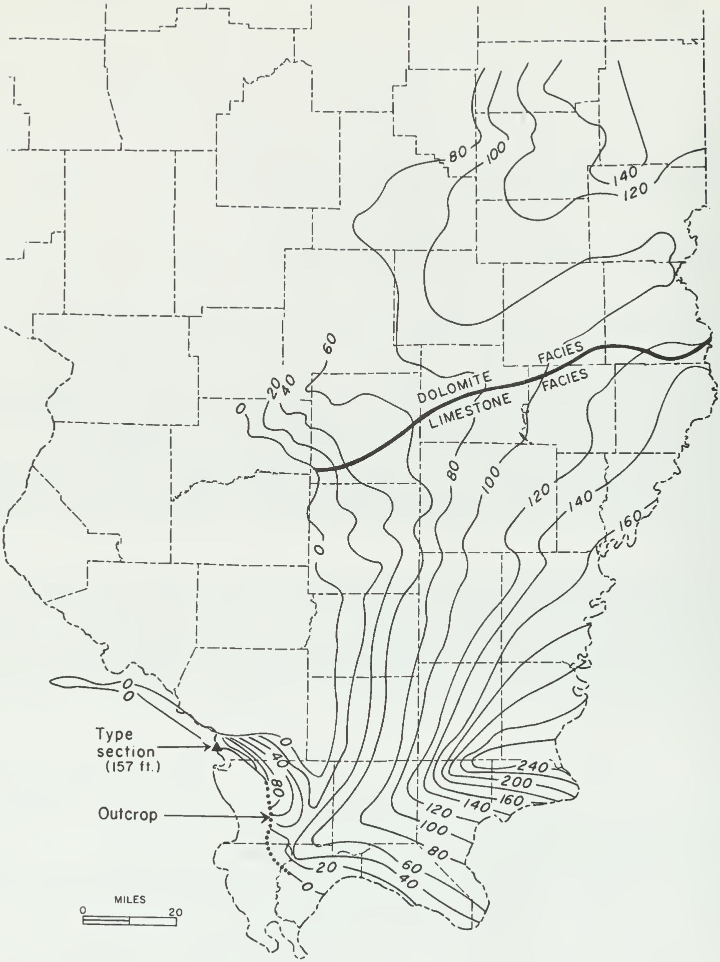


Figure 7
Thickness of Grand Tower Limestone in Illinois (from North, 1969).

structural trench, the "Wittenberg Trough," between the Sparta Shelf on the north and the Ozark Dome on the south. The original limits of this trough are conjectural because only a handful of down-faulted slices are preserved. General relationships of Devonian Formations around the Ozark Dome indicate that the Grand Tower lapped onto the Ozark Dome, but did not cross it (Charles Collinson, personal communication, 1985). It definitely reached at least to the vicinity of Farmington, St. Francois County, where chert containing Middle Devonian fossils was found in a diatreme that cut Lamotte Sandstone (Tarr and Keller, 1933).

The Grand Tower in Missouri and southern Illinois is a thick bedded to massive, fossiliferous, crystalline limestone with occasional lenses of chert. Floating sand grains are common. A thin but widely persistent zone of lenticular sandstone or very sandy limestone at the base of the Grand Tower is referred to as the Dutch Creek Sandstone Member. The sand grains of the Dutch Creek, as well as the floating grains higher in the Grand Tower, are frosted and well rounded, similar to those of the St. Peter Sandstone. They are presumably derived from the St. Peter and older sandstones that were exposed to erosion on the flanks of the Ozark Dome when the seas withdrew at the end of early Devonian time (Smunt, 1964; Summerson and Swann, 1970; and Collinson, 1967).

Joseph Devera (personal communication, 1985) thoroughly analyzed the petrology and paleoecology of the Grand Tower Limestone in the "Wittenberg Trough." He concluded that the limestone in the trough, as elsewhere, was deposited on a shallow marine shelf above a storm-wave base. Evidence of shallow deposition includes abundant stromatoporoids, worms, clams, corals, and various encrusting organisms. Tempestites (thin zones of storm-tossed shell debris) are conspicuous. Oscillating water depth is indicated by hardgrounds and local paraconformities. Aside from rounded, "floating" quartz sand grains, no transported extraneous material occurs within the Grand Tower. If a deep, fault-bounded trench had existed, we would expect fragments of the wall rock to be incorporated into the Grand Tower. (Such fragments are present, for example, in the younger St. Laurent Formation.) These findings indicate that the "Wittenberg Trough" is a structural and erosional artifact, not a depositional feature dating from Devonian time.

Beauvais Sandstone. Overlying the Grand Tower Limestone in the fault slice near Ozora is the Beauvais Sandstone (Weller and St. Clair, 1928). The presently known extent of this sandstone is limited to scattered outcrops within the fault zone in Ste. Genevieve County, and to sporadic occurrences in the subsurface of Illinois a few miles east of St. Louis (Koenig, 1961). The Beauvais is unknown in the outcrop belt of Illinois. Like the Dutch Creek, the Beauvais is composed of frosted, well rounded sand grains similar to those of the St. Peter. Its maximum thickness is approximately 50 feet (15 m), and its contacts with adjacent formations appear to be conformable.

The facts mentioned above prompted Croneis (1944) to question the identity of the Beauvais Sandstone. He suggested that the Beauvais might be equivalent to the Dutch Creek, in which case the "Grand Tower" at Ozora would be a lateral facies of the Clear Creek Chert. This idea has superficial merit from the standpoint of physical stratigraphy, but fails when paleontology is

considered (Collinson, 1967; and Tissue, 1977). No geologist since 1944 has promoted the Croneis "alternate" correlation of the Devonian of Missouri.

Tissue (1977) thoroughly examined sedimentary structures and petrology of the Beauvais, Dutch Creek, and other Middle Devonian sandstones of the Illinois Basin. He concluded that Beauvais sand was deposited primarily by tidal currents, which winnowed silt and mud and carried them to deeper waters. He also found the Beauvais petrographically identical to the Dutch Creek. Both sandstones exhibit bimodal grain-size distribution: a fine subangular fraction is mixed with larger, well rounded and frosted grains. Tissue favored provenance from St. Peter and older sandstones, and hypothesized that the wind played a role in transporting the grains.

St. Laurent Limestone. The name St. Laurent is applied to limestone overlying the Beauvais Sandstone, or where the sandstone is absent, to limestone directly overlying the Grand Tower Limestone in southeastern Missouri. The St. Laurent is equivalent to the Lingle and Alto Limestones of Illinois (Collinson, 1967). This nomenclature has been revised from time to time; current practice is to restrict "St. Laurent" to Missouri.

The St. Laurent reaches a thickness of at least 275 feet (84 m) and consists primarily of dense, brittle, gray to bluish gray, thinly bedded limestone. Within the unit, chert is common, as are argillaceous and arenaceous beds. In the fault slices near Ozora, chert- and limestone-pebble conglomerates or breccias are found in the lower part of the St. Laurent. Pebbles are rounded to angular and up to several inches in diameter. Evidently, they are derived, at least in part, from older formations (Croneis, 1944). Derivation from the uplifted Sparta Shelf immediately to the north is suggested.

Lingle and Alto Formations and Equivalents. The Lingle (older) and Alto Formations overlie the Grand Tower Limestone in southwestern Illinois, and thus correlate with the Beauvais Sandstone and St. Laurent Limestone in Missouri. The Lingle and Alto are lithologically heterogeneous, including limestone, dolomite, shale, siltstone, and chert. Together they are approximately 100 to 200 feet (30 to 60 m) thick in the study area. Their age and correlation are well established from fossil evidence (Orr, 1964; Collinson, 1967).

North (1969a, 1969b) divided the Lingle Formation into four members. The basal Howardton Limestone Member is fossiliferous, argillaceous limestone topped by a distinctive intraformational microbreccia composed of pebble-size or smaller, light-colored limestone fragments in a darker calcareous matrix. The Howardton, which thickens eastward into the Rough Creek Graben, is the only member of the Lingle traced that far east (North, 1969b). The overlying Tripp Limestone Member is very argillaceous or silty, cherty limestone interbedded with calcareous shale. Next is the dark gray, silty, calcareous Misenheimer Shale Member, and then the dolomitic, silty, cherty Walnut Grove Limestone Member, with the thin but persistent Rendleman Oolite Bed near the base.

The presence of calcareous breccia, intraformational conglomerate, stromatoporoids, and oolite beds in the Lingle Formation indicate that the Lingle, like the Grand Tower Limestone and Beauvais Sandstone, was deposited in shallow marine water (North, 1969).

The Alto Formation, which overlies the Lingle, is composed of silty, dolomitic limestone containing abundant chert, and calcareous or dolomitic shale and siltstone. The Alto reaches a maximum thickness of about 70 feet (21 m) (North, 1969b).

The three upper members of the Lingle, together with the Alto Formation, grade laterally into pyritic, black, fissile shale in the deep part of the Illinois Basin. This black shale represents the lower portion of the New Albany Shale Group, which in Illinois includes several dominantly dark, organic-rich shale formations of Middle and Late Devonian age.

• Upper Devonian Series

Dark gray to black shales of the New Albany Shale Group represent the Upper Devonian in the study area. The New Albany is part of the extremely widespread deposit of organic-rich Upper Devonian shale, found in much of the eastern United States. Devonian black shale is interpreted as having been deposited under anaerobic conditions in quiet water of a deep marine basin and basin slope (Cluff et al., 1981). The main source of mud is believed to be the lands that were being uplifted in the Acadian orogeny, which culminated in Late Devonian time.

The New Albany Shale Group reaches a maximum thickness of 460 feet (140 m) in the Rough Creek Graben near the Illinois-Kentucky border (Cluff et al., 1981). The unit thins westward, ranging from 50 to 100 feet (15 to 30 m) thick along the Ste. Genevieve Fault Zone in Illinois and within downdropped blocks of the fault zone in Missouri. It is much thinner on the Sparta Shelf, where it pinches out westward. Boreholes north of the fault zone in Perry County, Missouri, reveal 7 to 42 feet (2 to 13 m) of New Albany Shale; the unit has not been recognized in Ste. Genevieve County north of the fault zone. Whether this westward thinning is due to erosion, nondeposition, or both is not clear. The local presence of New Albany Shale, however, does indicate that at least the eastern portion of the Sparta Shelf was below sea level in Late Devonian time.

• Summary of Middle and Late Devonian History

The sea largely withdrew from southern Illinois and southeastern Missouri at the end of the Early Devonian; large areas were exposed to erosion. As shallow seas returned to the region, residual eroded and/or windblown St. Peter sand was reworked and deposited as the Dutch Creek Sandstone Member. Life flourished and carbonate production boomed in the well agitated, well oxygenated shallow sea of Grand Tower time. The western end of the Rough Creek Graben subsided gently; the Sparta Shelf remained above sea or rose slightly. The Ste. Genevieve Fault Zone was coming into action. Abrupt

changes in thickness of the Grand Tower near the zone may reflect this tectonic activity; however, no depositional "Wittenberg Trough" is indicated in Grand Tower time.

Major upheaval of the Sparta Shelf brought Grand Tower sedimentation to a close. The shelf tilted like a trap door, hinged on the east and raised on the west. Its southern margin was the ancestral Ste. Genevieve Fault Zone. The uplifted lands immediately were attacked by erosion, furnishing large quantities of clastic sediment to the neighboring sea. This is the source of the clay, silt, sand, and conglomerate in the Beauvais, St. Laurent, Lingle, and Alto Formations.

The sediments eroded from the Sparta Shelf contained very little sand. That is why the Beauvais Sandstone is so limited in distribution. Most sand in the Beauvais probably is reworked Dutch Creek/Grand Tower sand. Formations between the Grand Tower and the St. Peter Sandstone contain much silt and clay, but virtually no well rounded quartz sand (Summerson and Swann, 1970). Erosion on the Sparta Shelf probably never reached the St. Peter Sandstone, although the Ozark Dome may have contributed St. Peter sand to the Beauvais. The late Middle Devonian ocean of southeastern Missouri-southwestern Illinois received a great deal of clay and silt mixed with a little sand, most of which had already undergone several cycles of erosion and redeposition. This sand stayed in shallow water near the shoreline where it was reworked by the tides and left to form Beauvais Sandstone. The finer sediments were carried farther offshore and incorporated into the Lingle and Alto Formations. Probably not much of this detritus reached the deep, anoxic basin that developed around the west end of the Rough Creek Graben. The black muds deposited here were derived mainly from the Acadian highlands far to the east.

The conglomerates or breccias of the St. Laurent Limestone testify strongly to the adjacent, recurrent uplift that was taking place. The peculiar intraformational microbreccia of the Howardton Member of the Lingle Formation may have similar origin. The scarcity of sand in the St. Laurent probably reflects absence of sand in the uplands undergoing erosion. Most Dutch Creek sand had already been removed and placed into the Beauvais Sandstone.

By late Devonian-early Mississippian time, uplift had virtually ceased on the Sparta Shelf, and either the entire region subsided or sea level rose. This allowed the quiet, stagnant waters of the New Albany sea to encroach and deposit dark organic mud around the margins of the shelf. Some areas may have risen enough to prevent deposition or allow removal of New Albany Shale, but for the most part, the region was quiet until Mississippian sedimentation began.

Mississippian System

• Kinderhookian Series

Kinderhookian strata are thin and localized along the Ste. Genevieve Fault Zone. They crop out rarely, and cannot be distinguished in most well records. In the outcrop belt of southwestern Illinois, Kinderhookian limestone and shale are up to 2 1/2 feet (0.8m) thick (Collinson and Scott,

1958). Similarly, in Missouri near the Ste Genevieve Fault Zone, Kinderhookian beds are thin, discontinuous, and known only from widely scattered surface exposures.

• Valmeyeran Series

At the start of Valmeyeran time, a deep basin developed in southernmost Illinois, while the Sparta Shelf and region farther north held carbonate banks. The sharp line of demarcation between these contrasting environments intersects the Ste. Genevieve Fault Zone very near the Mississippi River. West of this line are crinoidal, bioclastic cherty limestones and minor calcareous shales of (in ascending order) the Fern Glen, Burlington, Keokuk, and Warsaw Formations. In Illinois, the Valmeyeran basin deposits commence with the very silty Springville Shale. This represents bottomset beds of the great Borden Siltstone delta, which prograded westward but did not quite reach southwesternmost Illinois (Lineback, 1966). Overlying the Springville Shale are the cherty, highly siliceous, sparsely fossiliferous limestones of the Fort Payne Formation. Only the thin edge of the Ft. Payne reaches southwestern Illinois. At the base of the Ft. Payne in northern Union County is a prominent ridge-forming ledge of massive chert. Above the Ft. Payne is the Ullin Limestone, a fine- to coarse-grained, crinoid and bryozoan-rich limestone. The Ullin is composed largely of detrital carbonate swept into the deep basin from surrounding shelves (Cluff and Lineback, 1981).

Through the remainder of Valmeyeran time, carbonate deposition continued in a broad, shallow, warm sea centered in southeastern Illinois. The Salem Limestone, 100 to 300 feet (30 to 90 m) thick in the study area consists mainly of biocalcarenite probably laid down in a setting similar to that of the Bahama Banks (Baxter, 1960). The overlying St. Louis Limestone is 150 feet (45 m) thick and typically a lithographic to finely crystalline, dark cherty limestone with interbedded oolitic limestone, dolomite, and evaporites. Its depositional environment was probably shallower, warmer, and more saline than that of the Salem Limestone (Lineback, 1972); however, both Salem and St. Louis contain several cycles of upward-shoaling facies, indicating fluctuations of sea level (Cluff and Lineback, 1981). The Ste. Genevieve Limestone above the St. Louis is oolitic biocalcarenite, probably of similar origin as the Salem Limestone. Thus, the Ste. Genevieve marks the beginning of a transition from the totally marine sedimentation of Valmeyeran time to the alternating marine/nonmarine cycles of the Chesterian Epoch. This limestone also contains lenticular bodies of sandstone, the first significant appearance of sandstone in the study area since the Middle Devonian.

• Chesterian Series

The Chesterian Series comprises numerous alternating formations of limestone, sandstone, and shale; the aggregate thickness of these strata ranges from 800 to 1,270 feet (245 to 387 m) in southwestern Illinois. The thickness in Missouri is less because the top of the series has been eroded. Chesterian rocks represent a variety of shallow-marine, tidal-flat, lagoonal, coastal, deltaic, and fluvial environments. The terrigenous clastics were

provided mainly by a large southwestward-flowing river system, which Swann (1963) called the Michigan River. According to Swann, cyclic Chesterian deposition reflects repeated advance and retreat of the sea, coupled with lateral migration of the delta of the Michigan River along the shoreline; the prevailing longshore currents flowed from southeast to northwest.

Isopach and facies maps of individual Chesterian formations largely support Swann's overview. The patterns are complex, but the general trend is to thicker sandstones and greater fluvial-deltaic sedimentation in the northeast, and to greater marine influence in the southeast. Two notable exceptions are seen in the Aux Vases and Degonia Sandstones. The Aux Vases is the oldest Chesterian sandstone (or youngest Valmeyeran, in Swann's scheme), while the Degonia is the youngest Chesterian sandstone. Both sandstones thicken southwestward, toward the Ozarks (Willman et al., 1975). One might surmise that moderate uplift took place in the Ozarks during Aux Vases and Degonia time, inducing accelerated erosion and shedding of sand to adjacent seas. However, other than thick sand deposits, there is little evidence to support such hypothesis. Cluff and Lineback (1981) found that petrography and sedimentary structures of the Aux Vases Sandstone indicate aeolian, not fluvial, transport of the sediments. Potter's (1963) similar studies on the Degonia Sandstone indicated southwestward transport of sediment, despite the thickness variations.

• Mississippian-Pennsylvanian hiatus

A major unconformity marks the base of the Pennsylvanian System throughout the Illinois Basin. This unconformity is widespread in the central and eastern United States, it divides the Kaskaskia Sequence below from the Absaroka Sequence above (Sloss et al., 1949). It also marks a period of major activity along the Ste. Genevieve Fault Zone.

Bristol and Howard (1971 and 1972), using thousands of oil-test records, carefully mapped the sub-Pennsylvanian erosional surface throughout the Illinois Basin. Their maps reveal a system of anastamosing channels, up to 450 feet (140 m) deep and 20 miles wide, eroded into Mississippian and older strata. The channels trend generally southwestward and cross most of the present structural features without apparent deviation. One exception to this pattern is at the Du Quoin Monocline, where paleostreams appear to be deflected from southwestward to southward courses. This implies that the Sparta Shelf was a positive area in latest Mississippian and early Pennsylvanian time. Elsewhere the regional tilt was to the southwest, so that the pre-Pennsylvanian sediments were least eroded in southern Illinois; whereas progressively older units are eroded to the north and east.

This tilting is not detectable in outcrop or within small study areas (covering a few townships). Pennsylvanian strata are essentially parallel with underlying Mississippian beds, except along the margins of sub-Pennsylvanian valleys, where extensive paleoslumping of Chesterian strata has occurred (Bristol and Howard, 1972). Angular unconformities are known in only two places: the northern end of the La Salle Anticlinal Belt, and adjacent to the Ste. Genevieve Fault Zone in Jackson and Union Counties, Illinois.

Ekblaw (1925) was the first to establish the presence of faulted, tilted Chesterian strata, overlain by horizontal or gently dipping rocks of the basal Pennsylvanian Formation, in the vicinity of Alto Pass, Union County. St. Clair (1917a) previously suspected that such structures existed. Subsequently, many workers (Weller and Ekblaw, 1940; Desborough 1957, 1961a, 1961b; Pickard, 1963; Porter, 1963; and Satterfield, 1965) have mapped and described the structures in more detail. Unfortunately, no one has presented a detailed structural synthesis of the entire region. Some reports treat the whole area in general terms, and others present detailed investigations of single quadrangles.

Disrupted Chesterian rocks crop out northeast of the Rattlesnake Ferry Fault, which is the main or master break in the Ste. Genevieve Fault Zone of Illinois. The Rattlesnake Ferry Fault cuts Chesterian rocks, and so is clearly post-Mississippian. No Pennsylvanian rocks have been found adjacent to or southwest of that fault. The obvious, post-Mississippian, pre-Caseyville faults are small; most are displaced less than 100 feet (30 m). Tilted Chesterian rocks, some dipping 60° or more, are overlain by horizontal or gently dipping Caseyville strata. The actual contact is rarely visible in the field, but enough can be observed to establish the relationships.

Additional details on this episode of deformation are presented in the section on structural geology.

Pennsylvanian System

• Caseyville Formation

The oldest Pennsylvanian rocks in southern Illinois are assigned to the Caseyville Formation. The Caseyville is largely, perhaps entirely, Morrowan. Springeran rocks have not been identified in the Illinois Basin (Willman et al., 1975). Sandstone is the dominant lithology of the Caseyville, followed by siltstone, shale, claystone, thin and lenticular coal beds, and very minor limestone. Characteristic Caseyville sandstones are thick, massive, or cross-bedded cliff formers. They are relatively pure quartz sandstones that commonly contain well rounded granules and pebbles of white quartz. Such pebbles generally distinguish the Caseyville, because they are absent in Chesterian sandstones and rare in younger Pennsylvanian sandstones.

The Caseyville is dominantly a fluvial and deltaic deposit with little marine sediment. Specific environments include distributary channels, point bars, tidal channels, interdistributary bays, flood plains, marshes, and swamps (Koeninger and Mansfield, 1979). Basal Pennsylvanian sediments were laid down on the channelized, gently subsiding pre-Pennsylvanian erosional surface.

Pennsylvanian rocks today occur entirely northeast of the Rattlesnake Ferry Fault. The occurrence of Caseyville Formation closest to the fault is about 1/4 mile (0.4 km) near Alto Pass. No Pennsylvanian strata are known near the Ste. Genevieve Fault Zone in Missouri.

Figure 8
Large float block of chert-pebble conglomerate at base of Caseyville Formation on Fountain Bluff, about 1 mile (1.6 km) northeast of Ste. Genevieve Fault Zone, Jackson County, Illinois.

Several lines of stratigraphic evidence indicate

1. the Rattlesnake Ferry Fault formed a prominant scarp in Morrowan time;

2. the fault zone continued to move while Morrowan sediments accumulated;

3. post-Morrowan movements, if any occurred, would have been minor.

Fountain Bluff (fig. 10) is a large outlier of Caseyville Formation on the Mississippi River flood plain north of Grand Tower, Illinois. The southwest edge of the bluff is approximately 1 mile (1.6 km) northeast of the Ste. Genevieve Fault Zone. Pennsylvanian rocks tilt about 5° to the northeast and unconformably overlie upper Chesterian rocks that dip up to about 25° northeast. The gentle dip of Caseyville rocks attests to minor post-Caseyville uplift to the southwest.

On the west side of Fountain Bluff, the Caseyville Formation has a basal conglomerate of a type not found elsewhere in the Illinois Basin. Angular and subangular pebbles and cobbles of chert and silicified limestone, up to several inches in diameter, are set in a matrix of poorly sorted sand with limonitic cement (fig. 8). Fossils in the clasts range in age from early Silurian to Chesterian (Poor, 1925). These clasts, which must have come from the southwest, were probably transported by short streams over a steep gradient. It can be readily inferred that they came from uplifted lands southwest of the Rattlesnake Ferry Fault, which probably formed a prominent scarp at that time.

Further evidence of the presence of this fault scarp in Morrowan time is provided by Desborough (1961b), who extensively measured crossbedding orienta-

Figure 9
Sandstone of Caseyville Formation showing numerous high-angle normal faults, in natural exposure just south of Pomona. Faults die out upward within the exposure and most do not penetrate visibly beneath the weathered surface of the rock. Scale 5 ft (1.5 m).

tion in Caseyville sandstone near the fault zone. About 2 miles (3 km) northeast of the Rattlesnake Ferry Fault, crossbedding indicates southwestward flow, matching regional transport direction throughout Illinois. Closer to the fault, however, foreset beds abruptly change to a southeastward dip. Desborough surmised that the fault scarp deflected the regional flow of early Pennsylvanian streams from southwestward to southeastward.

Desborough (1961a) also reported several localities in the Pomona Quadrangle where older Caseyville strata are tilted and faulted, but overlain by undeformed younger Caseyville rocks. We revisited several of his localities, and confirmed his observations. For example, a cliff face on the east side of a stream (SW SW, Section 4, T 10 S, R 2 W) exposes slightly tilted thin-bedded sandstone and silty shale, horizontally overlain by massive sandstone. Numerous small high-angle normal faults penetrate the lower rocks, but most are truncated at the base of the massive sandstone. Another good locality is a ravine in the same section (NE NE SE), where pebbly Pennsylvanian sandstone dips 20° to 25° southeast and is overlain with angular unconformity by flat-lying, fine-grained sandstone. A small fault can be seen in the stream bed just below the unconformity; drag indicates reverse movement. A third site is a Caseyville cliff face in the Cobden Quadrangle just south of Pomona (NE NE SW, Section 28, T 10 S, R 2 W). Numerous steep normal faults cut the lower part of the cliff and die out upward (fig. 9). Although the faults clearly

displace laminae in the sandstone, close examination reveals that the fault planes are entirely healed; no open fractures penetrate the rock. The faults exhibit no gouge, slickensides, or breccia, and are visible only because of differential weathering of the sandstone. The faults must have formed before the sand lithified--a conclusion entirely in agreement with the other evidence.

Abbott Formation. The youngest Paleozoic strata near the Ste. Genevieve Fault Zone belongs to the Abbott Formation of Atokan age. The Abbott and Caseyville are similar in lithology and depositional history, but sandstones of the former contain more feldspar, mica and clay, and fewer quartz granules or pebbles than sandstones of the latter. Mapping the Abbott-Caseyville contact requires recognition of individual members, which can be difficult under the usual (poor) mapping conditions. Little detailed study has been performed on the Abbott Formation in southwestern Illinois.

The Abbott conformably overlies the Caseyville and exhibits only a very gentle, regional northeastward dip. No faults are known to penetrate it. Most exposures of Abbott Formation, however, are far enough from the Ste. Genevieve Fault Zone that they may be beyond the area of older deformed rocks. Whether the Abbott Formation ever was deposited southwest of the Ste. Genevieve Fault Zone cannot be determined from available evidence.

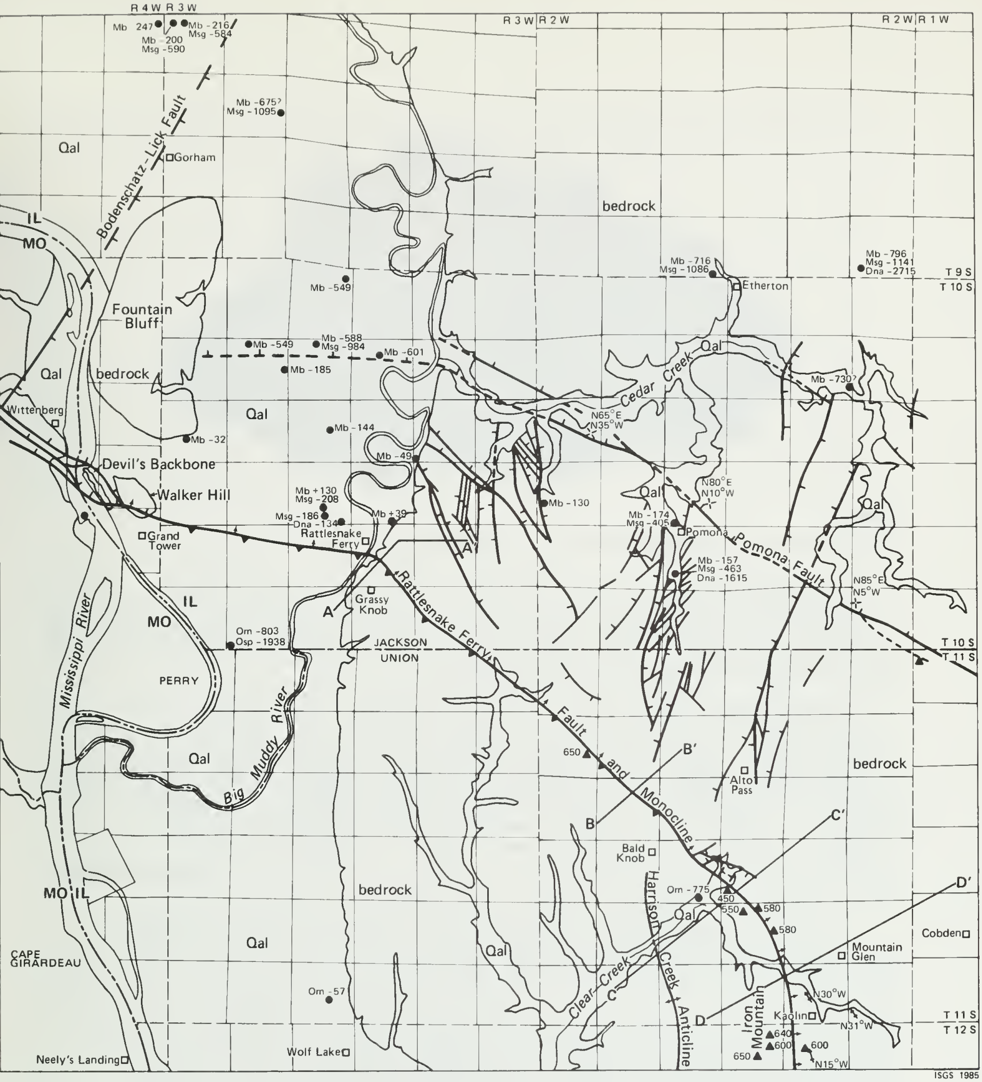
Tertiary System

• Eocene (?) Series

In Union County, Illinois, near the southeastern terminus of the surface trace of the Rattlesnake Ferry Fault are scattered occurrences of iron-cemented conglomerate and uncemented gravel, sand, and lignitic clay, tentatively believed to be of Eocene age. Locations where these materials have been found or reported are given in figure 10. Although the ages and origins of these deposits are not precisely defined, they do help to fix the time of the last structural movements in the Ste. Genevieve Fault Zone.

The most common deposit is iron-cemented conglomerate. Figure 11 is a photograph of a typical specimen. The grain sizes range from sand to cobbles several inches in diameter, and are dominantly dense, dark gray to bluish gray chert mixed with a few pebbles of quartz. Most grains are well rounded to subrounded; some of the smaller ones are more angular. No sorting, grading, or stratification is evident. The limonitic or hematitic cement ranges in color from yellow-brown to dark red to very dark brown, and is extremely tough.

We found the iron-cemented conglomerate most abundant near the crest of Iron Mountain and on the unnamed ridge that is a northward extension of Iron Mountain west of the village of Mountain Glen. We saw no deposits in situ, but several appeared to be nearly in place. Masses of the conglomerate occur within 20 or 30 feet (6 to 9 m) of the top of the ridge where they show through the cover of loess and colluvium. In places, conglomerate has broken off and rolled or washed down the slopes and into steep ravines. We observed



Qal Quaternary alluvium

● borehole, elevation (ft) at top of unit

Mb	Beech Creek Limestone (Chesterian)
Msg	Ste. Genevieve Limestone
Dna	New Albany Shale
Om	Maquoketa Shale
Osp	St. Peter Sandstone

reverse fault, tic on upthrown side

fault, tic on downthrown side

anticline

monocline

N85°E N5°W systematic fractures

N30°W calcite-filled fractures

▲ 650 outcrop of Eocene(?) gravel, elevation in ft

A—A' line of cross section (figs. 20, 21)

0 2 4 mi

0 2 4 6 km

Figure 10

Structural features of Ste. Genevieve Fault Zone, Jackson and northern Union Counties, Illinois.

Figure 11
Eocene (?) iron-cemented conglomerate from Iron Mountain, Union County, Illinois.

only one major stream with conglomerate in its bed (NE SW SW, Section 22, T 11 S, R 2 W): a tributary of Clear Creek is actively undercutting a steep bank at the northern end of the ridge, and pieces of conglomerate from the top of the cut bank are sliding into the stream.

Uncemented gravel and sand clearly related to the conglomerate have also been observed. Iron-cemented conglomerate is found up to an elevation of about 640 feet (195 m) near the crest of Iron Mountain (SW NE NE Section 3, T 12 S, R 2 W). Above this, loose sand and gravel appear in the heads of steep gullies. The gravel is similar to that in the conglomerate, except for the absence of cement. The sand is composed of poorly sorted, clear to translucent, mostly subrounded quartz grains. Evidently this is a remnant of a thick deposit, cemented only at its base. Unconsolidated sands and gravels may actually be common, but easy to overlook in the field.

Deposits of kaolinitic clay were mined during the early 20th century near the now-abandoned village of Kaolin (Section 36, T 11 S, R 2 W). The clay pits now are filled with water. When they were still being actively worked, St. Clair (1917b) and Parmalee and Schroyer (1921) described their geologic characteristics. Clays occurred in bedded deposits up to 90 feet (27 m) deep, overlain by or interbedded with sand, gravel, and small amounts of lignite, and topped by Pleistocene loess. Sand and chert gravels were commonly cemented by limonite or hematite, as are the gravels atop Iron Mountain. The same relationships have been observed at other localities away from the clay pits, and are recorded in unpublished field notes by various geologists of the Illinois State Geological Survey.

The age of these sediments has not been established conclusively, but the best evidence points to an Eocene age. Pamalee and Schroyer (1921) found the clays at Kaolin similar in lithology to deposits in the Eocene Wilcox Group at Mayfield, Kentucky. Lamar (1948) considered the Union County clays to be

Cretaceous, but admitted his evidence was "largely inferential." Aureal T. Cross (personal communication, 1984) examined spores from lignite taken from cast-off dumps at Kaolin and tentatively called them Eocene.

All geologists who studied the clays agreed that they are water-laid deposits protected from erosion by their placement in large sinkholes within the limestone bedrock. Clearly the rounded gravels have been transported by streams. Because the gravels are coarse and unsorted, they were probably carried by large streams with moderate gradients typical of uplands, rather than of coastal regions. Several hundred feet of relief was present, as is shown by finding iron-cemented conglomerate at 640 feet (145 m) elevation on Iron Mountain, while clay in the pits was up to 400 feet (122 m) elevation. The drainage pattern at that time differed considerably from today's. Most Eocene (?) sediments were later carried away by erosion. We cannot speculate much on the source of the gravels, but the dense, dark chert most resembles chert of the Lingle, Alto, and certain Mississippian Formations. The light-colored vesicular or "worm-eaten" chert characteristic of the Lower Devonian is conspicuously absent.

Evidence suggests that the gravel postdates movement along the Ste. Genevieve Fault Zone. Iron-cemented conglomerate, very nearly in situ, is found at elevations of 550 to 580 feet (168 to 177 m) on both sides of the ridge that runs northward from Iron Mountain. The underlying bedrock dips about 20° eastward, so the more-or-less horizontal gravel overlies it unconformably. Also, an isolated conglomerate deposit occurs at 650 feet (198 m) in elevation in a stream immediately southwest of the Rattlesnake Ferry Fault in the NE SE, Section 7, T 11 S, R 2 W, about 2 miles northwest of the summit of Bald Knob. Satterfield (1965) reported finding Eocene (?) gravel at an elevation of 600 feet (183 m) in the NW NW, Section 6, T 11 S, R 1 W. The second location is more than 6 miles (9.7 m) northeast of the fault and the underlying (Caseyville) bedrock was downthrown more than 2,500 feet (760 m) relative to the bedrock (Clear Creek Chert) at the first locality.

Quaternary System

Pleistocene Series. Bedrock along the Ste. Genevieve Fault Zone is mostly covered with unconsolidated Pleistocene deposits, mainly loess, alluvium, and colluvium. These materials conceal much evidence on the nature and origin of faulting.

The Pleistocene (Illinoian) glaciers did not quite reach the fault zone. The nearest deposits of till are about 5 miles north of the Rattlesnake Ferry Fault in Jackson County, Illinois (Desborough, 1961a). The Missouri River closely marks the southern limit of glaciation.

Upland areas are mantled with loess (windblown silt) derived from river valleys during interglacial stages. Loess is thickest--up to several tens of feet--on the eastern bluffs of the Mississippi River and gradually thins eastward. West of the river, it is no more a few feet thick. On steep slopes loess has been washed and mixed with weathering products of rocks to form colluvium. Good exposures of loess are rare.

Valley fill consists partly of glacial outwash but is mainly recent alluvium. Several lengthy segments of the Ste. Genevieve Fault Zone underlie the flood plain of the Mississippi River, and many faults pass beneath alluvium of smaller streams. There is no evidence of structural disturbance in any alluvium.

Terrace remnants that are present along some streams in the fault zone are potentially useful for determining whether Quaternary tectonic movements have occurred. Russ (1984) examined terraces believed to be 17,000 to 19,000 years old along the Ste. Genevieve Fault Zone in Missouri. He found no evidence of offsets or structural disturbances. We did not recognize any terraces straddling the fault zone in Illinois. Only small remnants of terraces remain along a few of the streams in Union and Jackson Counties. Some are formed of glacial outwash; whereas others consist of glaciolacustrine sediments (Lineback, 1979).

STRUCTURAL GEOLOGY

Ste. Genevieve Fault Zone

The Ste. Genevieve Fault Zone is a complex structural feature, composed of numerous individually named and unnamed faults. In this section we describe the zone, proceeding from its northwestern end in Missouri to its southeastern end in Illinois.

• St. Clair Fault Zone

The northwesternmost mapped structure that may be related to the Ste. Genevieve Fault Zone is the "St. Clair Fault" (McCracken, 1971). Because it comprises at least four faults with an aggregate width of several miles, the term "fault zone" appears more appropriate than "fault." The four faults form a pair of chevrons pointing northwest between St. Clair and Stanton, Franklin County, Missouri (McCracken, 1971; Anderson, et al. 1979) (fig. 2). Published maps show the faults displacing the Gasconade, Roubidoux, and Jefferson City Formations (lower Ordovician) and thin overlying Pennsylvanian strata. The rocks within the two chevrons are downthrown relative to those outside.

We examined structurally disturbed rocks exposed in roadcuts along Interstate Highway 44, adjacent to the rest area between St. Clair and Stanton, and within the St. Clair Fault Zone. We agree with McCracken (1971) that many solution-collapse features, which are abundant in this part of Missouri, are being referred to as faults. Strata in the roadcuts dip as steeply as 50°, but the attitudes of tilted blocks and of the broken zones that separate them are not consistent. There are large zones of breccia, composed of rubbly chert with blocks of sandstone in a sandy or claylike matrix. Shales and siltstones of the Roubidoux Formation are contorted and jumbled together with masses of chert and sandstone.

The only features that suggest tectonic faulting are inconspicuous, vertical to steeply dipping planar fractures observed in relatively undisturbed outcrops of Roubidoux Sandstone. Several fractures showed small offsets and slight drag indicative of normal movement. The fractures are neither

regularly spaced nor entirely consistent in trend, but most of them strike east-west to east southeast-west northwest, more or less in line with the Ste. Genevieve Fault Zone to the southeast. Other fractures strike in a northeasterly direction.

If the Ste. Genevieve Fault Zone is related to the St. Clair, then it is possible tectonic movements in the Ste. Genevieve fractured the bedrock, enhanced solution of carbonate rocks underlying the bedrock, and resulted in the development of the unusually large paleo-karst structures that comprise the St. Clair Fault Zone.

Ditch Creek Fault System. Warfield (1953) mapped, described, and named the Ditch Creek Fault System in the northeast quarter of the Richwoods Quadrangle, Franklin County (fig. 2). These northwesternmost faults can definitely be linked with the Ste. Genevieve Fault System. The Ditch Creek consists of several faults that are largely displaced downward to the northeast. Maximum vertical separation is approximately 180 feet (55 m). The faults dip steeply; Warfield asserts that they are normal. A sharp, narrow monocline follows the largest fault, and continues beyond the northwestern end into Section 9, T 40 N, R 2 E. Away from the immediate fault zone the strata are essentially horizontal.

Remarkably coarse breccia is found in the Ditch Creek Fault System. Warfield describes blocks of bedded dolomite up to 15 feet (4.6 m) across, jumbled together with smaller blocks and fragments in a matrix of pulverized rock. The faults containing the breccia have only a few tens of feet (10 to 20 m) of displacement. The blocks in the breccia are from the same upper Cambrian and lower Ordovician dolomites that border the fault zones. No such megabreccias have been noted elsewhere in the Ste. Genevieve Fault Zone.

Valles Mines-Vineland Fault Zone. The Valles Mines-Vineland Fault Zone is the southeastward continuation of the Ditch Creek Fault System (fig. 2). Parizek (1949) mapped the former as a series of subparallel faults; the faults with the greatest offset displaced strata downward to the northeast. Maximum throw reaches 800 feet (245 m) near Vineland Crossing; displacement decreases both northwestward and southeastward. The largest faults are vertical or steeply dipping, as shown by their nearly linear traces across hills and valleys. Accompanying the narrow main fault zone is a monocline, along which bedding is locally vertical. Rocks along the fault zone show intense drag and wide zones of gouge or breccia; sandstone has been altered to quartzite, and dolomite recrystallized to a texture resembling marble.

Good exposures of the fault zone are available in cuts along the Missouri Pacific Railroad near Vineland Crossing. About 1/2 mile (0.8 km) southwest of the crossing, thin-bedded dolomite and shale of the Davis Formation are virtually flat-lying and unfractured on the upthrown side of the fault zone. Northeast of this, shattered Potosi (?) Dolomite dips 15° to 30° northeast. The fault separating the two exposures is concealed in a narrow ravine. A second large fault, also concealed, lies northeast of the former fault and southwest of the crossing. Poorly exposed Potosi (?) Dolomite is found in a cut within a few hundred feet of flat-lying Jefferson City Dolomite on the downthrown side of the fault.

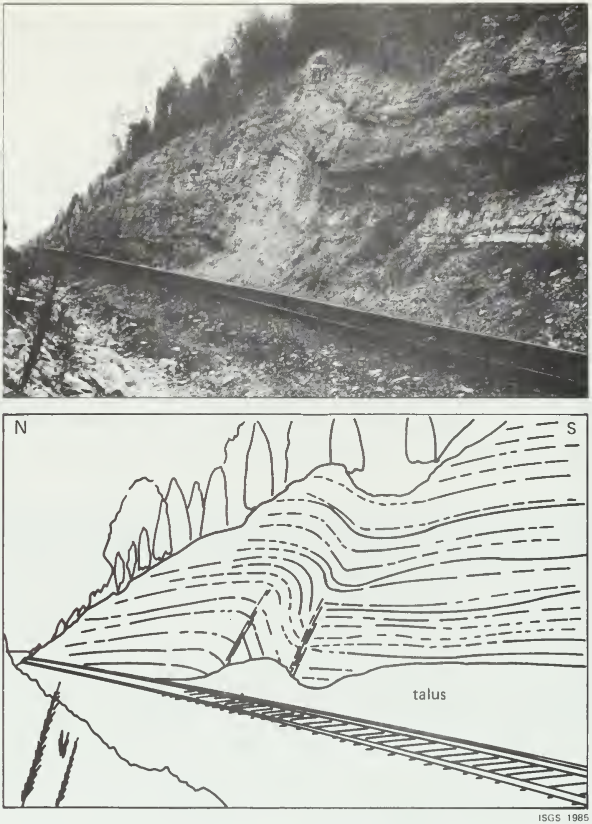


Figure 12
Reverse flexure in Jefferson City Dolomite in railroad cut northeast of Vineland Crossing, Jefferson County, Missouri. Flexure dies out upward and steepens slightly downward. On opposite side of railroad cut, the structure is a thrust fault that passes upward into a monocline. This structure is northeast of main faults of Ste. Genevieve Fault Zone and has opposite direction of throw.

Many small faults are visible in the downthrown Jefferson City Dolomite in the large railroad cut just northeast of Vineland Crossing. All but one are normal faults that strike N 60° W to N 75° E (subparallel to the two large faults) and dip 75° or more. These faults show little or no drag, generally contain little or no breccia, and have throws ranging from less than 1 inch to about 15 feet (4.6 m). Among these numerous normal faults is a single reverse fault. It strikes N 83° E and dips 27° to 33° north on the northwest wall of the cut; the north side is upthrown. The fault has about 3 feet of vertical separation at track level and dies out upward into a broad flexure. On the southeast wall of the railroad cut, this fault appears as a wide, sharp, complex flexure (fig. 12). The flexure hinges are nearly vertical at the bottom of the cut; upward the dip and the amount of offset decrease.

Structure seen in roadcuts on U.S. Highway 67 at Valles Mines is similar to that at Vineland Crossing. The main fault zone is largely hidden by talus now, but it was described by Gibbons (1974) when exposures were fresher. Gibbons showed two parallel high-angle reverse faults that bring Potosi Dolomite on the southwest up against Jefferson City Dolomite on the northeast; the faults are spanned by a gentle monocline. Roadcuts north of the main fault zone still display several very steep normal faults. One has a breccia zone about 4 feet (1.2 m) wide, and another showed vertical slickensides. As at Vineland Crossing, these normal faults strike nearly parallel with the adjacent reverse faults.

The displacement of the Valles Mines-Vineland Fault Zone decreases toward the southeast. Whether surface faults connect directly with the main Ste. Genevieve Fault Zone is not certain because exposures are poor and the area has never been mapped in detail. The Valles Mines-Vineland Fault Zone lines up directly with the main Ste. Genevieve Fault Zone, however, and shows the same structural style.

Richwoods-Cruise Mills-Fertile Fault Zones. The Richwoods Fault Zone of Warfield (1953) and the Cruise Mill-Fertile Fault Zone of Parizek (1949) are interconnected and link northwestward with faults mapped by Burgehardt (1952). These faults lie 3 to 5 miles (5 to 8 km) southwest of and strike parallel with the Ditch Creek and Valles Mines-Vineland Faults (fig. 2). They are high-angle normal faults with the southwest side downthrown as much as to about 350 feet (110 m). Thus, the displacement is opposite to that of the Ditch Creek and Valles Mines-Vineland Fault Zones. Intense drag and brecciation were observed in stream cuts. The faulting apparently dies out on the southeast and does not extend into Ste. Genevieve County.

Faulting in Ste. Genevieve County, Missouri. The Ste. Genevieve Fault Zone appears near the St. Francois-Ste. Genevieve County line, aligned with the Valles Mines-Vineland Fault Zone; and then it extends southeastward to a point about 3 miles (5 km) south of Weingarten (fig. 2). There the zone turns abruptly turn to the east and maintains this heading into Perry County. The bend near Weingarten is the first of several sharp curves in the fault zone.

The southeast-trending portion of the zone is narrow, increasing in throw toward the southeast. Cambrian and Lower Ordovician rocks are displaced. The best exposure, although it has deteriorated badly, is in the Illinois-Missouri Railroad cut just southwest of Weingarten. Gibbons (1974) described the zone there as comprising two reverse faults, dipping 70° and 75°, and having the southwest side upthrown 900 to 1,150 feet (275 to 360 m). Lamotte Sandstone on the southwest is juxtaposed with Jefferson City Dolomite on the northeast. The former has been extensively crushed and displays a breccia zone about 50 feet (15 m) wide. Spanning the fault zone is a monocline with the limb vertical at its steepest point. Several small normal faults with a few inches to several feet of displacement strike parallel to the reverse faults on the upthrown block.

East of Weingarten where the fault zone turns eastward, it becomes wide and complex. Near the village of Ozora the faults outline a series of diamond-shaped blocks in map view. For this location, Weller and St. Clair

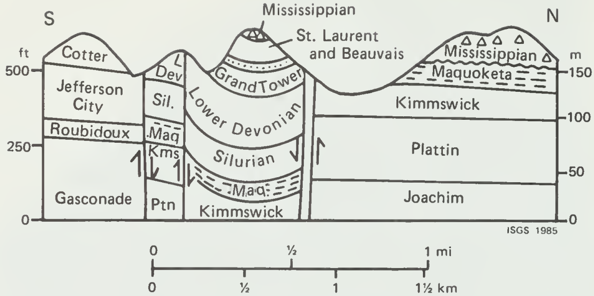


Figure 13
Cross section of Ste. Genevieve Fault Zone near Ozora, Missouri, illustrating an unconformity between basal Mississippian strata and Maquoketa Shale north of the fault zone. (Modified from Weller and St. Clair, 1928.)

(1928) demonstrated two periods of faulting, the first Devonian in age, the second post-Mississippian.

North of the fault zone, basal Mississippian strata rest directly on Cincinnatian (upper Ordovician) Maquoketa Shale (fig. 13). The entire Silurian and Devonian Systems have been eroded. Immediately south of the northernmost fault in the zone, Mississippian limestone overlies a complete section of Devonian and Silurian rock. The fault juxtaposes Kimmswick Limestone on the north with Bailey Limestone on the south, for a throw of approximately 1,000 feet (300 m) at that level. The Mississippian rock, however, crops out at nearly the same elevation on both sides of the fault. These relationships indicate that faulting took place after deposition of the St. Laurent Formation and before that of the basal Mississippian units.

Weller and St. Clair (1928) reported that the fault surface was visible in a ravine and described it as a normal fault dipping steeply southward.

From Ozora the Devonian faults trend westward, their displacement decreasing. Two or more subparallel faults, joined by many oblique cross-faults, have been mapped. The zone turns northwestward near Weingarten, and continues as far as the Ste. Genevieve-St. Francois county line. These Devonian faults run parallel with the reverse faults mentioned previously, but their throw is opposite: the southwestern side is downthrown (fig. 2). Exposed faults are vertical or high-angle normal with a maximum throw of approximately 350 feet (110 m) (Weller and St. Clair, 1928).

Devonian faults continue eastward from south of Ozora, but are concealed by Mississippian rocks and Quaternary alluvium. Logs of boreholes north of the fault zone show a major unconformity beneath the Mississippian, while the complete Devonian section lies within the fault zone. North of the fault zone, the amount of missing section decreases eastward, indicating that uplift was less to the east.

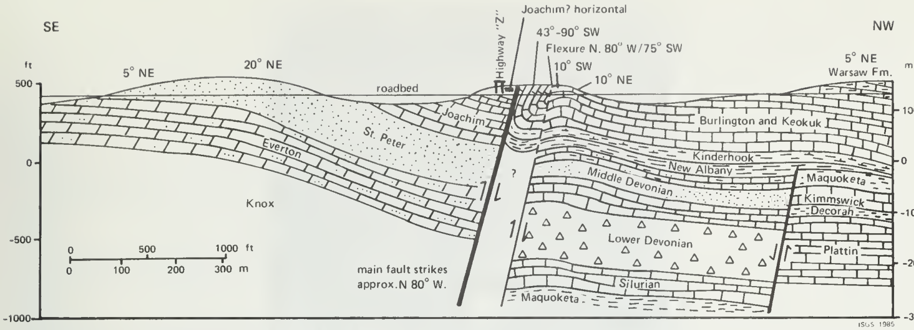


Figure 14 Cross section of Ste. Genevieve Fault Zone at roadcuts on Interstate Highway 55 southeast of Ozora, Missouri. Dip of bedding, as measured in roadcuts, is given at ground surface. The buried fault of late Middle Devonian age, northwest of the main fault, is shown for illustration only; it is not exposed at the surface. About 6 miles (10 km) north of this point, roadcuts show basal Mississippian rocks resting unconformably on Ordovician.

Faults in the central and southern parts of the Ste. Genevieve Fault Zone near Ozora displace Mississippian rocks, and therefore, are of post-Mississippian age. Displacements on these are mainly downward to the north and are greater than displacements on Devonian faults (fig. 13). The largest fault, which is near the south edge of the zone, is apparently a steep reverse fault. Other post-Mississippian faults also dip steeply. Weller and St. Clair (1928) state that in places Devonian faults have been offset by post-Mississippian faults. Elsewhere, the reverse is true; post-Mississippian faults appear to have followed and exploited the Devonian faults.

Southwest of Ozora, where the fault zone is widest, the individual fault slices are nearly horizontal or only gently tilted. The fault slice within which Middle Devonian limestone was quarried by the Ozora Marble Company is unusual because it dips southwestward, back toward the main fault. The maximum dip observed trends southwest, striking N 50° E. East of Ozora the fault zone abruptly narrows, and the beds along the zone tilt steeply toward the north. In several exposures they are vertical or even overturned adjacent to the largest fault. These observations illustrate a consistent pattern: the narrower the Ste. Genevieve Fault Zone, the sharper and steeper is the associated flexure.

The new roadcuts on Interstate Highway 55, approximately 3 miles (5 km) southeast of Ozora, provide an excellent view of the fault zone where it is narrow and sharp. Displacement essentially is confined to a single fault. The roadcuts are found adjacent to the interchange with County Highway "Z" at milepost 141 on Interstate 55 (Thacker and Satterfield, 1977).

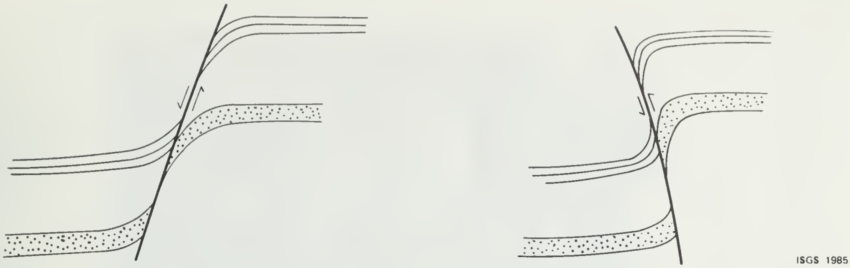
Southeast of the interchange, St. Peter Sandstone is exposed on the upthrown side of the fault (fig. 14). It is gently folded from nearly horizontal at the southeast end of the roadcut to a dip of about 20° north at the northwest end. Three main sets of fractures are present. One set is roughly horizontal or parallel to bedding. It is completely silicified; the silica is white and stands out in relief on the weathered surface of the rock. The

Figure 15
Silicified fractures in St. Peter Sandstone on upthrown side of Ste. Genevieve Fault Zone, roadcuts of Interstate Highway 55, Ste. Genevieve County, Missouri. There are three sets of fractures: one nearly parallel with bedding, a second set trending WNW (parallel with the large fault), and the third set striking NE. The latter two sets of fractures are vertical or steeply dipping. Photograph shows small normal offsets of the first two sets of fractures by the northeast-trending fractures.

second set of fractures is nearly vertical and strikes N 60° to 70° W, nearly parallel with the main fault; these also are silicified. The third set strikes N 40° to 60° E and is vertical or steeply dipping; most of these fractures are open, but a few are silicified. Fractures of the third set offset the first two, with very small normal displacements. Therefore, the third set of fractures is youngest (fig. 15).

On the downthrown side of the fault, Burlington-Keokuk Limestone (middle Mississippian) is folded into a very sharp flexure, the hinge of which is visible on both sides of the highway and strikes N 80° W. South of the hinge, the beds are vertical or overturned. The degree of rotation increases southward, toward the main fault. The most severe overturning noted was on the slab that dipped 43° south, rotated 147° from its original horizontal attitude. This slab was seen in the roadcut beside the south-bound lanes immediately north of the fault. North of the hinge, Mississippian rocks dip gently. They are tilted about 20° NE beside the northbound lanes and form a gentle arch beside the southbound lanes.

Another part of the Ste. Genevieve Fault Zone can be seen just north of the overpass along the southbound lanes. Rubble of brecciated St. Peter Sandstone and Joachim (?) Dolomite lies immediately south of overturned Burlington-Keokuk Limestone. The sandstone is highly shattered and



Drag on a normal fault. Drag tends to pull the beds parallel with the fault plane. Maximum dip on a normal fault thus is 60–75 degrees.

Drag on a reverse fault. Beds dragged in direction of movement tend to become parallel with fault; i.e. vertical or overturned. The compressional element involved in reverse faulting also tends to make the drag more pronounced than it is on a normal fault with the same throw.

Figure 16
Diagram illustrating relationship of angle of fault plane to maximum dip of beds in fault zone.

recrystallized. In most specimens, the original grains as well as the bedding have been obliterated. The dolomite is fractured, but less intensively than the sandstone; orange laminations can be seen. If we have correctly identified the formations, the vertical separation is the fault in roughly 2,000 feet (600 m).

Although the fault surface cannot be observed in section here, the fact that the strata are overturned on the downthrown side is powerful evidence for reverse movement (fig. 16).

Several large roadcuts northwest of the Highway "Z" interchange show Burlington, Keokuk, and Warsaw Formations dipping less than 5° northward and broken by steep normal faults with, at most, a few feet of throw.

Faulting in Perry County, Missouri. In Perry County, Missouri, the Ste. Genevieve Fault Zone strikes eastward to the Mississippi River bluffs at McBride, and then curves to a heading of S 50° E until it crosses the river at Wittenberg. Structure of the zone is well exposed at several places between McBride and Wittenberg. The faults that can be seen in outcrop apparently are of post-Mississippian age. Devonian faults lie to the north, concealed by younger deposits.

Gibbons (1974) described the fault zone at McBride. Although he gave the displacement of the main fault as 1,000 feet (300 m), that figure is too small. St. Peter Sandstone on the south is faulted against Aux Vases Sandstone (uppermost Valmeyeran or lowermost Chesterian), for an indicated throw of 3,000 to 3,500 feet (910 to 1,070 m). The actual fault is not exposed, but Mississippian strata close to it are overturned as much as 135°. A small reverse fault dipping 70° NE is visible in St. Peter Sandstone in a roadcut on Missouri Highway 51. The direction of throw of this fault is opposite to that of the main fault.

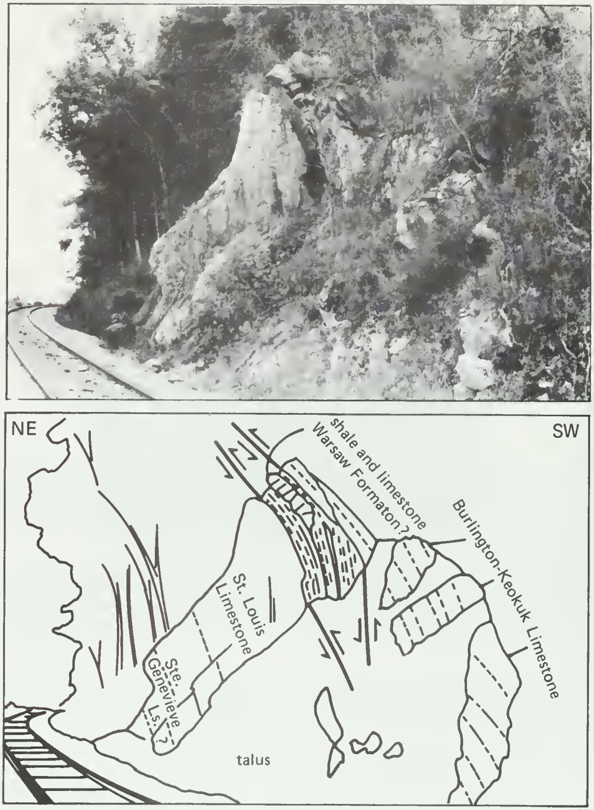


Figure 17 ISGS 1985

High-angle reverse fault in railroad cut at Red Rocks Landing, Perry County, Missouri. The fault strikes southeast and has the southwest block upthrown several hundred feet. This is the largest fault in the Ste. Genevieve Fault Zone to have the actual fault surface clearly exposed.

Reverse faulting is clearly demonstrated at Red Rocks Landing in railroad cuts and natural exposures (accessible only at low water) on the Mississippi shore. We re-examined these outcrops, which were previously described by Flint (1925 and 1926) and Gibbons (1974). Two large parallel faults are evident; they strike northwest-southeast. The southwestern fault is hidden by alluvium and brings Bailey Limestone on the southwest adjacent to Valmeyeran rocks on the northeast, for a throw of roughly 1,000 feet (300 m). The second fault can be seen in the railroad cut and projected to the river bank (fig. 17); it is a reverse fault dipping 70° SW and having the southwest side upthrown several hundred feet. Burlington or Keokuk Limestone on the upthrown

block is in contact with uppermost St. Louis or lowermost Ste. Genevieve Limestone on the downthrown block. Beds on both sides of the fault strike and dip parallel with the fault plane and thus are overturned. The fault zone contains blocks of limestone and sheared greenish to buff shale, possibly from the Warsaw Formation. Faint vertical slickensides were observed at one place on the fault surface; another surface showed definite striations and mullion plunging 65° NE. These indicate either some left-lateral movement or slight rotation of a fault slice. The St. Louis or lowermost Ste. Genevieve Limestone adjacent to the second fault appears to be extensively recrystallized.

Northeast of the second fault are excellent exposures of bioclastic and oolitic limestone and calcareous sandstone of the Ste. Genevieve and lower Chesterian formations. The beds strike northwest and dip 35° to 70° SW. Both the stratigraphic succession and the attitude of crossbedding in oolitic limestone indicate that the strata have been overturned.

Railroad cuts northwest of the landing, on the upthrown side of the fault zone, show Bailey Limestone striking north-northwest and dipping 33° to 40° NE. A series of steep reverse faults with throws of a few inches are evident. The faults strike N 20° W to N 20° E and their west sides are upthrown. They are planar and exhibit no drag, breccia, or slickensides. A second set of planar fractures trends about N 45° E/90° and shows no displacement. Still farther northwest, Ordovician dolomite is nearly flat-lying and shows no systematic fracturing.

Between Red Rocks Landing and Wittenberg, the Ste. Genevieve Fault Zone was mapped by Flint (1925) and re-mapped by Amos (in press). The maps differ in detail but show the same basic structure. Along most of this stretch, the fault zone is composed of two or more subparallel high-angle faults between which is a belt of vertical to steeply overturned Mississippian strata. Chesterian rocks northeast of the fault zone dip gently northeastward, while Devonian and older strata southwest of the main faults dip northeastward at moderate angles (10° to 30°). In the Rockwood Quadrangle, Amos (personal communication, 1984) recognized many high-angle normal faults southwest of and parallel with the main reverse faults.

Amos (personal communication, 1984) also mapped a series of gently plunging anticlines and synclines southwest of the fault zone in the Altenburg Quadrangle. These folds strike north-northwest and thus lie en echelon to the fault zone. Amos suggested that these signify a left-lateral wrenching movement, but he also stated that folds northeast of the fault zone give a contradictary indication of right-lateral motion.

Rattlesnake Ferry Fault and monocline. The main fault of the Ste. Genevieve Fault Zone in Illinois is commonly known as the Rattlesnake Ferry Fault (figs. 2 and 10). The name, which was applied first by Weller and Ekblaw (1940), was taken from a now-defunct village on the Big Muddy River about 4 miles (6.4 km) east of Grand Tower. Although generally spoken of as a fault, the Rattlesnake Ferry structure actually is a faulted flexure or monocline. Faults, where present, follow the line of steepest dips on the northeast-dipping limb of the monocline. Since fold and faults clearly developed in the same tectonic activity, they are discussed together in this report.

The Rattlesnake Ferry Fault and monocline cross the Mississippi River into Illinois just north of Grand Tower, where they are partially exposed in bedrock hills (fig. 10). From Grand Tower, the structure continues on a heading of S 80° E, 4 miles (6.4 km) beneath the flood plain of the Mississippi River. It reappears in the bluffs at Rattlesnake Ferry, where its strike abruptly changes to S 40° E. From Rattlesnake Ferry to Bald Knob, a distance of about 7 miles (11 km), the deformed zone is narrow, the monocline dips steeply and is locally overturned, and the displacement on the fault is large. Surface faults splinter and die out rapidly southeast of Bald Knob, but the monocline continues on a heading of S 15° to 20° E for several miles farther south. The fold gradually becomes broader and gentler, its displacement decreases, and it loses its identity.

Structure at Grand Tower. Figure 18 is a geologic map of the Ste. Genevieve Fault Zone at Grand Tower. Structure is known from surface exposures of bedrock in the Devil's Bake Oven, the Devil's Backbone, Walker Hill, and Fountain Bluff. All these hills are isolated remnants or bedrock islands on the flood plain, created by repeated shifts in the course of the Mississippi River during Quaternary time.

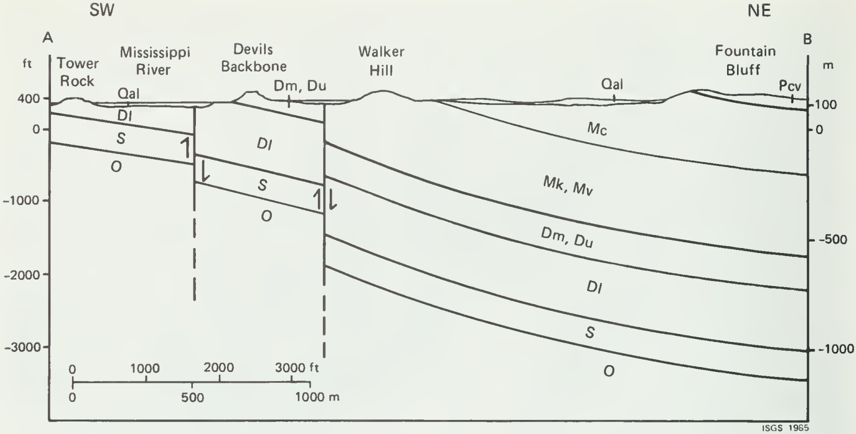
Two parallel faults, both downthrown to the northeast, are mapped in Missouri opposite Grand Tower (Amos, personal communication, 1984). These trace to the two faults that straddle the Devil's Bake Oven and most of the Devil's Backbone. The southern of the two faults cuts the southern end of the Backbone on a heading of S 80° E. This fault displaces Grand Tower and Lingle Limestone on the north against Clear Creek Chert and Backbone Limestone on the south, for a stratigraphic offset of approximately 450 feet (137 m) downward to the north. The fault surface is not visible, but exposures are sufficient to indicate that it dips steeply. The other large fault is entirely covered by alluvium between the Backbone and Walker Hill. The existence of this fault is indicated by the fact that measured dips of strata on Walker Hill and the Devil's Backbone are not great enough to account for differences of elevation of strata on the two hills. The throw on the fault is probably 350 to 400 ft (105 to 125 m.) with the northeast side downthrown (fig. 19).

The two faults merge and cross the southern end of Walker Hill on a bearing of slightly south of east. The displacement of this fault, 800 feet (245 m) downward to the north, equals the sum of throws on the two faults that straddle the Backbone. Grand Tower Limestone (Middle Devonian) is juxtaposed with Valmeyeran Salem Limestone (middle Mississippian). The main fault surface is not visible in outcrop, but small faults or fractures in Salem Limestone may be observed immediately north of the fault zone, they dip steeply and contain breccia and nearly vertical (dip-slip) slickensides.

Several small faults on Devil's Backbone trend east-northeast and thus run obliquely to larger faults nearby. The small faults are nearly vertical or steeply inclined normal faults showing no drag and little or no gouge, breccia, slickensides, or mineral fillings. Fractures or joints in the limestone are rare and not systematic except in the area of faults.

The monocline is relatively gentle at Grand Tower (fig. 19). Dips range from 15° to 25° on the Devil's Backbone, from 12° to 23° on Walker Hill north of the fault, and about 10° or less on Walker Hill south of the fault.

Figure 18
Geologic map of the Ste. Genevieve Fault Zone at Grand Tower, Illinois. Line of cross section A–B shown on figure 19.



Qal	QUATERNARY alluvium		DEVONIAN
	PENNSYLVANIAN	Dm, Du	Middle and Upper Devonian Series
Pcv	Caseyville Formation	Dl	Lower Devonian Series
	MISSISSIPPIAN	S	SILURIAN
Mc	Chesterian Series	O	ORDOVICIAN
Mk, Mv	Kinderhookan and Valmeyeran Series		

Figure 19
Cross section of line A-B, figure 18, near Grand Tower, Illinois.

Changes in inclination are gradual. Steep dips, such as are common elsewhere along the Rattlesnake Ferry Fault, are not observed. In most cases, bedding strikes roughly parallel to the nearest large fault. The total uplift at Grand Tower is slightly more than 3,000 feet (910 m). Only about 800 feet (245 m), or 25 to 30 percent of the total, is due to faulting; the rest is due to folding. Width of the deformed zone is difficult to define. Rocks at both ends of the cross section (fig. 19) are gently tilted, but the dip flattens very gradually in both directions away from the fault zone.

From Walker Hill to Rattlesnake Ferry the fault zone and flexure are entirely concealed by Quaternary alluvium. The covered portion of the structure is approximately 3 1/2 miles long and bears S 80° E.

Structure near Rattlesnake Ferry. A cross section of the fault zone at Rattlesnake Ferry on the Big Muddy River (figs. 10 and 20) shows a strong monoclinal flexure cut by a large high-angle reverse fault with its southwest side upthrown. At the southwest end of the profile, approximately 1 mile (1.6 km) from the fault, essentially flat-lying Bailey Limestone forms prominent bluffs. The tilt of the strata increases gradually at first, then more rapidly as the fault is approached. Grand Tower Limestone, which is about 300 feet (90 m) southwest of the fault trace, dips 65° NNE. Immediately adjacent

to the fault, in a small ravine in the NE NE SW, Section 27, T 10 S, R 3 W, Lingle (?) Limestone is shattered and the bedding not discernable. The fault itself is buried under slopewash, but cannot be more than 100 feet (30 m) wide.

A ledge of Chesterian limestone in the same ravine, immediately northeast of the fault, is vertical to steeply overturned. The next in situ bedrock is Glen Dean Limestone which dips 35° NE. Within 600 feet (180 m) of the fault, this dip flattens to 10°. At 3,000 feet (910 m) from the fault zone, the dip is practically horizontal. The total width of the fold and fault zone is 7,000 to 8,000 feet (2100 to 2450 m), and the total vertical displacement is 2,900 to 3,000 feet (880 to 910 m). The strongly deformed zone (dips greater than 20°) is only about 2,000 feet (600 m) wide. Faulting accounts for 1,200 to 1,400 feet (360 to 420 m) of uplift and monoclinal flexure for the remaining 1,500 to 1,700 feet (460 to 520 m).

In contrast to Grand Tower, Rattlesnake Ferry shows a narrower and steeper flexure, a larger component of fault displacement, but slightly smaller total uplift.

A few interesting exposures are found just southeast of Rattlesnake Ferry. Steeply overturned Chesterian strata were observed in a northeast-trending ravine in the SW NW SE, Section 27, T 10 S, R 3 W. Nearby was a large boulder of fault breccia, containing angular fragments of Devonian chert and oolitic limestone with Mississippian fossils, held together by extremely hard, dark brown limonitic cement. Farther up the same ravine, outcrops of several Devonian formations were found in various structural attitudes, indicating complex faulting. Traces of galena were found in fractured limestone on the cast-off pile of a small prospect pit. Another good site of outcrops is found beside the gravel road in the S 1/2 SE SE, Section 27. Two faults outline a narrow slice in which steeply overturned St. Louis Limestone contacts gently dipping Bailey Limestone on the southwest and steeply dipping lower Chesterian strata on the northeast.

Structure near Bald Knob. A series of cross sections (fig. 21) have been prepared to illustrate structure of the Rattlesnake Ferry Fault and monocline near Bald Knob, in northern Union County. Cross-section B-B', drawn through the N 1/2, Section 17, T 11 S, R 2 W, shows Clear Creek Chert on the southwest faulted against Ste. Genevieve Limestone on the northeast, for a throw of roughly 1,300 feet (390 m). The structure of the upthrown block is poorly known, but available outcrops reveal gentle dips in the chert within a few hundred feet of the fault zone. The steepest dips on the downthrown block are 30° to 40°. At 1,000 feet (300 m) northeast of the fault they decrease to less than 10°. The profile shows Pennsylvanian rocks at their closest known exposure, only 1,200 feet (360 m) from the Rattlesnake Ferry Fault Zone. Basal Pennsylvanian sandstone dips very gently northeastward and overlies Chesterian strata with slight angular unconformity.

The total uplift is about 2,400 feet (730 m), of which approximately 55 percent is from faulting and 45 percent by folding. The deformed zone is roughly 3,000 feet (900 m) wide.

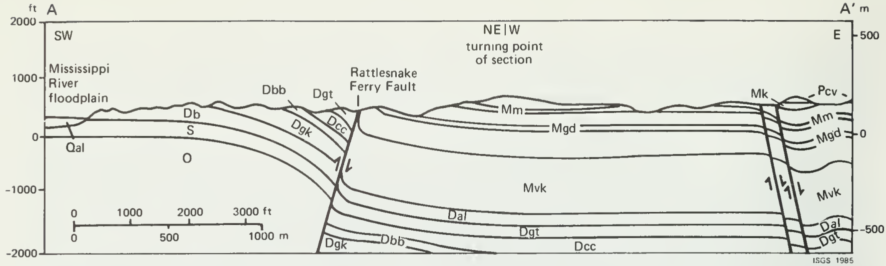


Figure 20 Cross section of Ste. Genevieve Fault Zone at Rattlesnake Ferry, Jackson County, Illinois. Line of cross section is shown on figure 10. No vertical exaggeration. Legend as for figure 21.

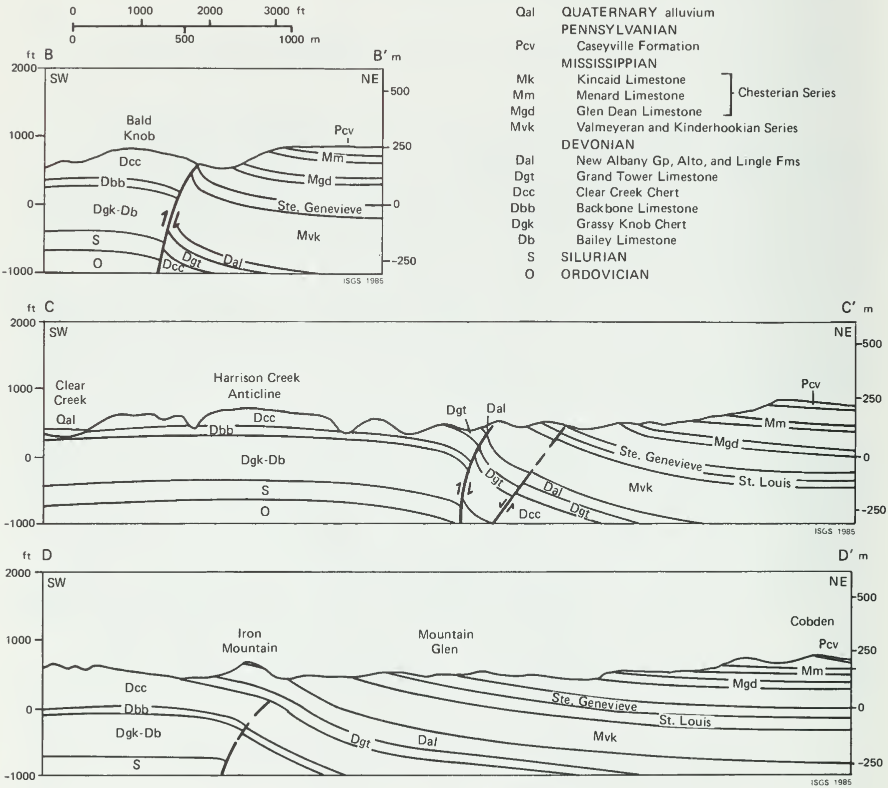


Figure 21 Cross sections of Ste. Genevieve Fault Zone in Union County, Illinois. Lines of cross sections are shown on figure 10. No vertical exaggeration.

In Sections 21 and 22, T 11 S, R 2 W, Union County, the Rattlesnake Ferry Fault splits and abruptly dies out east of the summit of Bald Knob. The monocline curves to a south-southeastward heading and continues in that direction, although it steadily widens and loses its identity southward.

The Rattlesnake Ferry Fault is a single break with more than 1,000 feet of throw in the SE SW, Section 16, T 11 S, R 2 W (fig. 10). Southeast of this point the fault zone splinters and rapidly loses displacement. Scarcity of outcrops and absence of subsurface data render interpretation speculative, but a complex pattern of tilted upthrown and downthrown fault slices is indicated. For example, at the end of the ridge adjacent to the road in the SE SE NE, Section 21, Salem Limestone strikes N 80° W and dips 25° north, but the offset northwestern extension of the ridge is covered with float of Chesterian sandstone and limestone. Blocks of Chesterian sandstone also occur on the spur ridge in the SE SW NW, Section 22, virtually surrounded by outcrops of older formations. A ledge of Aux Vases (?) Sandstone in the NE NE, Section 21, changes dip rapidly and is cut off abruptly at both ends. The pattern of faults resembles three outstretched fingers with several cross faults connecting the two longer fingers (fig. 10).

Figure 21, C-C' is a cross section from southwest to northeast across the tips of the "finger faults." Compare this profile with B-B', the section 2 1/2 miles (4 km) to the northwest. The total uplift in B-B' is about 2,300 feet (700 m), only slightly less than the 2,400 feet (730 m) in B-B'; but the offset in C-C' is accomplished almost totally by folding rather than faulting. The monocline is much broader in C-C' than in B-B' (7,500 feet [2,300 m] vs. 3,000 feet [910 m]), and the angle of dip is correspondingly less. In both sections the upthrown block shows relatively little folding. Most of the flexure takes place in the downthrown northeastern block.

No faults with significant displacement have been recognized in the field along the Rattlesnake Ferry trend south of the line shown in cross section C-C'. Nevertheless, sizeable undetected faults may exist. Construction of a cross section D-D' through Iron Mountain and Mountain Glen (fig. 10), 1 1/2 to 2 miles (2.4 to 3.2 km) south of the line shown in C-C', revealed structure not evident in the field. Lowermost Valmeyeran strata near the crest of Iron Mountain dip 15° ENE; St. Louis Limestone (middle Valmeyeran) in the bed of Clear Creek 1,200 feet (360 m) east of Iron Mountain shows the same inclination. Geometric construction, using a dip of 15°, allows room for only about 250 feet (75 m) of section between the St. Louis and basal Valmeyeran beds. The actual thickness of that interval in nearby boreholes is at least 500 feet (150 m) to possibly more than 1,000 feet (300 m). Either a fault or a sharp flexure must be drawn to accommodate this thickness of section. We re-examined the critical area in the field, but found no additional outcrops that would clarify the problem. Valmeyeran limestones weather deeply by solution and do not crop out except in the beds of large streams. Faults, especially those parallel to strike of bedding, are easy to miss under such conditions.

Vertical or steeply dipping planar tension fractures thickly lined with calcite were observed in several outcrops of Mississippian limestone east of

Figure 22
Nearly vertical, wide, calcite-filled fracture in crossbedded bioclastic Salem Limestone, in railroad cut south of Kaolin, Union County, Illinois. Possible normal offset, down to east (right). Fractures project directly toward southern terminus of surface trace of Rattlesnake Ferry Fault.

Iron Mountain. The best examples were found in coarse-grained biocalcarenite of the Salem Formation in the railroad cut just south of the village of Kaolin (fig. 22). The fractures strike N 15° W and vary from a hairline to 6 inches (15 cm) wide; they are filled with coarse white calcite. Several definitely show offset laminations; the largest displacement measured was 15 inches (38 cm) downward to the east. Apparent striations or slickensides on several fracture surfaces consistently plunge 75° to 80° south, indicating some right-lateral movement along with the dominant dip-slip movement. Fractures observed on other outcrops are similar, but not quite as well developed; none showed provable offset. Nearly all fractures observed strike parallel to bedding of the rock, thus indicating tensional stress oriented normal to strike (fig. 10).

The total differential uplift shown in cross section D-D' of figure 21 is 1,700 to 1,800 feet (520 to 550 m), considerably less than the 2,300 feet (700 m) in cross section C-C' (fig. 21).

The southernmost place where the Rattlesnake Ferry monocline is clearly defined is in roadcut on Illinois Route 146, about 2 miles (3.2 km) west of Jonesboro in Union County (fig. 2). The roadcut in the NE NE NW, Section 23, T 12 S, R 2 W, reveals bedded rocks of the Lingle and Alto Formations dipping about 5° ENE. About 2,000 feet (600 m) eastward in the NE NE, Section 23, Springville Shale and Fort Payne Chert dip 3° to 4° ENE; similar dip is displayed by Grand Tower Limestone in stream-bank exposures a short distance southwest of the Alto-Lingle roadcut. George Fraunfelter (personal communication, 1984) told us that small faults were visible in Springville Shale, but now are covered by talus and vegetation. The rocks show prominent planar vertical fractures, systematic within individual beds, but not consistent in orientation from one bed to the next.

South of Jonesboro the Rattlesnake Ferry monocline loses its identity amid the gentle, regional dip from the Ozark Uplift to the Illinois Basin. This regional structure is expressed as the outward fanning of Mississippian and Devonian outcrop belts, as shown on the Geologic Map of Illinois (Willman et al, 1967). These slightly tilted Palezoic rocks are unconformably overlain by Cretaceous deposits at the head of the Mississippi Embayment in Alexander and Pulaski Counties.

Pomona Fault. The Pomona Fault was named by Desborough (1961a), who mapped it in the Pomona Quadrangle. Pickard (1963) subsequently extended the structure westward into the Gorham Quadrangle, while Satterfield (1965) traced it across the Cobden Quadrangle.

Our observations indicate that the Pomona Fault is not actually a fault at the surface, but rather a fractured, gentle monoclinal fold. To avoid the confusion of new terminology, we will continue to refer to the structure as the Pomona Fault.

The Pomona Fault (fig. 10) is based on the maps of the three authors cited above, and on our interpretation of subsurface data from the flood plain between the Big Muddy River and Fountain Bluff. The Pomona Fault lies 3 to 5 miles (5 to 8 km) northeast of the Rattlesnake Ferry Fault, and trends closely parallel to it.

Desborough, Pickard, and Satterfield all asserted that the Pomona structure is a fault, with its northeast side downthrown as much as 200 feet (60 m). Our field checks, however, failed to produce any evidence of significant offset at the surface. Instead, we found that rocks along the mapped "fault" trace are tilted northeastward, generally at 7° to 10° but locally up to 15°. In all cases examined, these dips were sufficient to account for the observed outcrop patterns without invoking faulting. The dips flatten to nearly horizontal within a few hundred feet on either side of the "fault" trace.

Well developed systematic jointing is found along the Pomona Fault. Johnson (1970) measured hundreds of sets of fractures and analyzed the resulting data. He found two strong sets trending approximately N 5° W and N 75° E, and a third, weaker set trending N 40° E. The same orientations were found on both sides of the fault along its length. The fact that nearly all joints observed were normal to bedding suggested that they developed prior to

folding and/or faulting. Johnson observed that the two main sets of fractures make conjugate angles to the third set, which is perpendicular to the Pomona Fault. Thus he concluded that the principal compressive stress responsible for fractures and faults was horizontal, with an azimuth of N 40° E; and that the Pomona Fault is a reverse fault.

We measured the orientations of fractures at several localities along the Pomona Fault. Our findings support Johnson's observations, if not his conclusions.

Two boreholes near the Pomona Fault indicate that displacement increases with depth. An oil test hole south of the fault in Section 28, T 10 S, R 2 W, and another north of the fault in Section 36, T 9 S, R 2 W, both reached New Albany Shale (fig. 10). The top of the Beech Creek ("Barlow") Limestone (Chesterian) was 639 feet (195 m) lower in the northern hole than in the southern. Elevation differences on the top of the Ste. Genevieve Limestone (Valmeyeran) and New Albany Shale (Upper Devonian), were 678 feet (207 m) and 1,100 feet (335 m) respectively. This difference in elevation suggests that the Pomona Fault has large offset in the basement and dies out upward through the sedimentary column. Another possibility is that recurrent uplift took place in Mississippian and Pennsylvanian time. The last movements, at least, were post-Morrowan, as the Caseyville Formation (Morrowan) is folded and fractured.

Lack of information about the dip of the fault plane(s) hinders structural interpretation of the Pomona Fault. Johnson's fracture data, however, do tend to favor reverse faulting over normal or strike-slip faulting. The consistent southwestward uplift and lack of en echelon folds further rule against lateral slip. If the Pomona Fault were produced by northeast-southwest horizontal compression, as Johnson inferred, the fault should be a low-angle reverse (thrust) plane, at least at depth. We suggest that the principal stress may have been vertical, causing the direct uplift of a basement block. The parallelism of the Pomona and Rattlesnake Ferry Faults strongly suggests not only that the Pomona is a branch of the Rattlesnake Ferry, but also that both developed during the same tectonic activity.

• Faults near Alto Pass

Extensive, although minor, faulting and related deformation have been mapped north and northwest of Alto Pass in Union and Jackson Counties, Illinois (fig. 10). Most known structures lie between the Rattlesnake Ferry and Pomona Faults, but some extend north of the latter. As recognized by St. Clair (1917a), the Alto Pass faulting is largely of post-Chesterian, pre-Caseyville age.

The mapped distribution of faults is shown in figure 10. This map may not reflect the true structural pattern. The figure is based on the maps of Desborough (1961a), Porter (1963), Pickard (1963), and Satterfield (1965) and has been modified by our field checking. Lack of time precluded checking all reported faults. Many of those inspected proved to be non-existent or inaccurately plotted. The dense fracture pattern south of the village of

Pomona is especially suspect. Apparently different mappers applied different criteria to recognizing faults and did not match structures at borders of quadrangles.

The known deformation is largely confined between the Pomona and Rattlesnake Ferry Faults, but the actual extent may be much greater. At least three factors contribute to scarcity of mapped faults northeast of the Pomona Fault:

1. surface rocks in this region are largely Pennsylvanian, but many faults are known to affect only pre-Pennsylvanian strata;

2. lack of reliable marker beds in the Pennsylvanian makes recognition of small faults difficult;

3. the area north of Cedar Creek is largely mantled with glacial drift.

The first two factors apply to Fountain Bluff as well, although pre-Pennsylvanian folding is known there. Small faults obviously project beneath the Mississippi flood plain, but much more densely spaced drilling than is currently available will be required to map them.

The faults that have been mapped show two preferred trends: N 0° E to N 25° E, and N 10° W to N 40° W. The former set dominates in the eastern part of the area; whereas the latter is more common to the west. The eastern side is downthrown on roughly half of the faults; the western side is downthrown on the others. Apparently a few underwent scissoring.

Not many fault surfaces are actually exposed, but those that are, with rare exceptions, prove to be high-angle normal faults. The few available examples of drag and slickensides record dip-slip movement. Displacements are small; the largest faults have throws in the vicinity of 100 feet (30 m). Faults visible in outcrop generally display offsets ranging from less than an inch (about 1 cm) to several feet (1 to 2 m).

Stratigraphic relationships show that movement began after deposition of Chesterian sediments, and was largely completed prior to accumulation of the Caseyville Formation. Some faults were formed during Caseyville sedimentation, and only a few were active after Caseyville time. Chesterian rocks are commonly observed to be tilted, folded, or faulted, but adjacent overlying Pennsylvanian beds are horizontal or very gently dipping and unfaulted. Chesterian dips of 10° to 35° are common; in one case, a tilt of 65° was measured. Pennsylvanian rocks, in contrast, rarely incline more than 10° and generally dip less than 5°. Several faults, which clearly displace Chesterian strata, do not visibly offset the Caseyville Formation above.

In places the Chesterian formations have been folded as well as faulted. In southern Jackson County, between Pomona and Rattlesnake Ferry, we were able to map several subparallel, elongate anticlines and synclines. The axes of these strike northwest to north-northwest and their noses plunge abruptly. Continuous exposures along streams reveal changes of dip in the

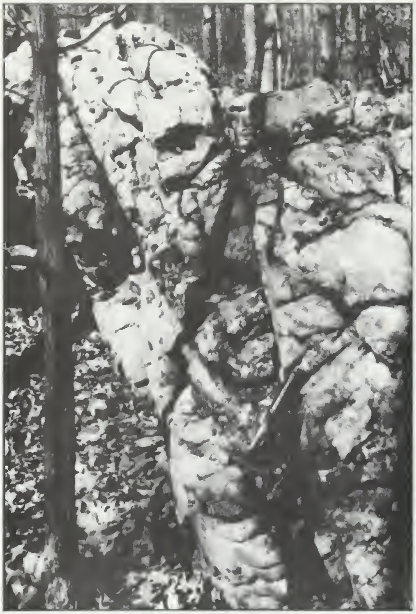


Figure 23
Degonia Sandstone cut by many high-angle fractures and small faults in natural exposure near southwestern corner of Pomona Quadrangle. Fractures do not appear to penetrate the interior of the rock, suggesting that they developed before the sand was fully lithified.

range of 20° to 35° within a lateral distance of only 300 feet (90 m). Faults in this area strike roughly parallel with the long axes of folds. Therefore, inclined beds do not merely reflect tilting of rigid fault blocks, nor do they merely represent drag adjacent to faults.

The Chesterian rocks appear, for the most part, to have been lithified when deformation took place. This is evidenced by locally intense, mineralized fracturing near faults and on hinges of folds. A counter-example, however, was found in the NW NE, Section 29, T 10 S, R 2 W, Pomona Quadrangle. Here is a fault striking N 25° E with its northwest side downthrown approximately 100 feet (30 m). Degonia Sandstone on the upthrown block is cut by numerous small normal faults that trend more or less parallel with the large fault. Close examination reveals that the small faults have no gouge, breccia, or slickensides, and do not penetrate the rock as open fractures, although they stand out sharply on the weathered surfaces (fig. 23). The faults are healed fractures, which apparently developed before the sand was fully lithified.

Faulting contemporaneous with Caseyville sedimentation can be documented at several places. A cliff of pebbly sandstone just south of Pomona, in the NE NE SW, Section 28, is cut by numerous north-northeast-striking high-angle normal faults (fig. 9). All these are healed fractures, like those described above in Degonia Sandstone. Furthermore, they can be seen to die out upward on the cliff face. Another example of Caseyville faulting can be seen along the east wall of the south-flowing ravine in the SW SW SW, Section 4, T 10 S, R 2 W, Pomona Quadrangle. Several dozen small, healed normal faults displace thin-bedded sandstone and sandy shale, which Desborough (1961a) mapped as the Drury Shale Member of the Caseyville Formation. Most of these faults are truncated at the base of the overlying Pounds Sandstone Member, and those that do extend into the Pounds die out upward. Yet another example is found in the ravine in the NW NE SE of the same section. Here conglomeratic sandstone and sandy shale, dipping 20° to 25° southeast, are unconformably overlain by horizontal Pounds Sandstone. Near the head of the ravine the lower beds, but not the Pounds Sandstone, are offset by a fault striking N 68° E and dipping 20° NW. Drag along this fault indicates thrusting, with the northwest side upthrown. This was the only well defined reverse fault we found among all of the Alto Pass faults.

At least some structures described above may have originated by slumping of unconsolidated sediments, but we propose that such slumping may have been triggered by tectonic movements.

Desborough (1961a) and others describe some faulting as post-Caseyville Formation, but we had great difficulty confirming the presence of any such faults. No faults have been mapped as cutting the younger Abbott Formation, but poor exposures, lack of marker beds, and cover of glacial drift inhibit mapping. Also, the crop line of the Abbott Formation lies northeast of the region where faulting appears to be well developed. The most we can say with assurance is that the Caseyville Formation has been gently tilted northeastward away from the Ste. Genevieve Fault Zone. This tilting may reflect movement in the fault zone, but is minor compared with deformation of pre-Pennsylvanian strata.

• Harrison Creek Anticline

The Harrison Creek Anticline (fig. 10) is a broad and gentle fold situated west of the southern part of the Rattlesnake Ferry monocline. The anticline trends in a general southward direction from the south side of Bald Knob in Union County to northern Alexander County, a distance of about 17 miles (27 km). Weller and Ekblaw (1940) named the Harrison Creek Anticline and described it in more detail than have any subsequent workers.

The anticline is known mainly from surface exposures. It is poorly defined because the Lower Devonian cherts, which lack marker beds and rarely form outcrops, comprise the bedrock along much of its course. The best expression of the fold is on Harrison Creek, in Section 16, T 13 S, R 2 W. Maquoketa Shale appears above stream level at the core of the anticline, and is overlapped by Silurian rocks and Bailey Limestone on the flanks. The maximum structural relief is thus 300 to 400 feet (90 to 120 m). The east

limb appears to be steeper; local dips of 10° to 12° were measured, in contrast to 5° to 6° on the west flank. The east limb is broken by the Atwood Fault (fig. 2).

On Clear Creek, just south of Bald Knob, the Harrison Creek Anticline can be mapped, but is extremely subtle. The Backbone Limestone rises above drainage at the crest, and is flanked by Clear Creek Chert. Maximum dip on the east limb is only 2 to 3°, while on the west limb the dip is too slight to measure.

Weller and Ekblaw (1940) postulated that the Harrison Creek Anticline may be a southward continuation of the Du Quoin Monocline, but we found no field evidence that the anticline extends north of Bald Knob.

• Atwood and Delta Fault and others

Weller and Ekblaw (1940) mapped three faults striking north-northwest and lying en echelon to one another in southern Union and northern Alexander Counties. They called the northern one the Atwood Fault and the southern one the Delta Fault, but the middle fault is yet unnamed (fig. 2). All three are mapped as having the east side downthrown; vertical separation reaches 500 feet (150 m) on the Atwood Fault.

Surface formations along these three faults are almost entirely Lower Devonian cherts. Outcrops are so scarce that it is difficult to prove the existence of the faults, much less acquire structural details. Our field studies tended to verify the presence of the Atwood and Delta Faults, but left the middle, unnamed structure entirely unverified (we could neither confirm nor disprove its presence).

The Atwood Fault, as mapped by Weller and Ekblaw (1940) brings Clear Creek Chert on the east (downthrown side) against Bailey Limestone and Grassy Knob Chert on the west. These formations can be distinguished, with some difficulty, on the basis of float and scattered outcrops. Mapping seemed to confirm the presence of structural offset, especially in the vicinity of Atwood Ridge (Section 33, T 12 S, R 2 W). The only tangible evidence of faulting was observed along Harrison Creek in the SE NW, Section 15, T 13 S, R 2 W, where weathered chert outcrops display dips of 10° to 15° eastward and contain steeply inclined sharp flexures or small faults with 1 to 2 feet (0.3 to 0.6 m) of throw. Value of these observations is weakened by the poor condition of the outcrops and the possibility of slumping or solution-collapse (more on this later). We also noted a slight alignment of stream valleys and ridges with the fault (as mapped).

The unnamed "middle" fault of Weller and Ekblaw straddles the Union-Alexander County line in Section 34, T 13 S, R 2 W and Section 3, T 14 S, R 2 W. It is mapped as having Grassy Knob Chert on the west upthrown against Clear Creek Chert on the east. We examined all bedrock exposures along the mapped trace, but found no indication of faulting, and could not reliably distinguish Clear Creek from Grassy Knob Chert. We did observe steeply dipping to vertical normal faults of small displacement (fig. 24) at an

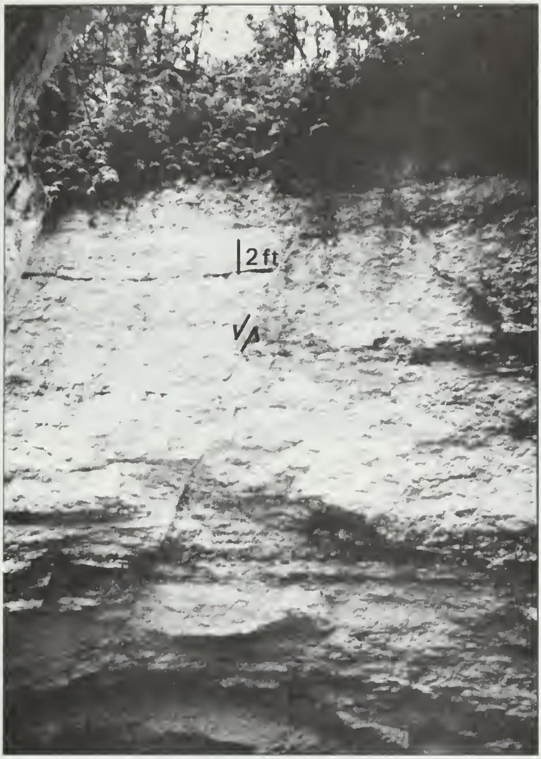


Figure 24
Small normal fault in Clear Creek Chert at abandoned silica quarry, NW SE Section 34, T 13 S, R 2 W, Union County, Illinois. Fault strikes N 20 E and has northwest side downthrown about 2 ft (0.6 m) at top of exposure; throw decreases downward.

abandoned silica quarry in the NW SE, Section 34. The quarry is approximately 1/4 mile (400 m) east of the supposed fault, so the significance of these small structures is debatable.

Weller and Ekblaw plotted the Delta Fault in the western part of T 14 S, R 2 W, Alexander County. We could not find a fault surface or demonstrate displacement, but we did find structural features that suggested a fault. Most notably, a nearly vertical ledge of chert crops out in a ravine in the NE NE NE, Section 20, T 14 S, R 2 W. The beds strike N 5° to 10° W and dip 75° to 83° SE. Elsewhere along the mapped fault line, we found systematic jointing or fractures: one set strikes NNW and the second set trends east-northeast to east-southeast. Two small, steeply dipping reverse faults were observed in the highwall of an active silica quarry approximately 1 1/2 mile (2.4 km) east of the trace of the Delta Fault.

Figure 25
Small anticline in Clear Creek Chert in roadcut, N½ SW Section 9, T 12 S, R 2 W, Union County, Illinois. Origin of structures like this is enigmatic in a rock that has been heavily altered by solution and silicification.

Small, unmapped and unnamed faults, folds, and fracture zones are common in southern Union and northern Alexander Counties. We made no effort to map these systematically. We visited many localities where structural features were mentioned in previous unpublished field notes of the ISGS. We also checked "outcrops of opportunity" in roadcuts, quarries, and along large streams. While we cannot present a true structural synthesis, we can state that a majority of exposures visited contained one or more features possibly of tectonic origin. Our findings suggest that the entire region has undergone complex, small-scale deformation.

Minor high-angle faults observed in silica quarries have been described already (fig. 24). These quarries operate(d) in Clear Creek Chert that has been altered to a white, chalky form of silica known as tripoli. Figure 25 is a photograph of a small anticline in a roadcut in Clear Creek Chert, in the N 1/2 SW, Section 9, T 12 S, R 2 W, Union County. This figure also illustrates the typical, deeply weathered condition of Lower Devonian chert. Such material is difficult to map or analyze structurally.

The Valmeyeran (middle Mississippian) carbonates that underlie much of eastern Union and Alexander Counties provide few useful exposures. These rocks, because they weather deeply by solution, produce a gently rolling topography. It is marked by many sinkholes and other features of karst topography and mantled by thick residual soil.

In contrast, many excellent exposures are found in shales and siltstones of the Alto and Lingle Formations, New Albany Group, and Springville Formation. These formations crop out in a belt running southward from Jonesboro to the Alexander county line, and then east-southeast to the edge of the Mississippi Embayment. Outcrops show widespread small-scale deformation. Structures observed include anticlines, synclines, monoclines, sharp flexures, and small high-angle faults. Dips of 10° to 15° are common; a dip of 70° was measured on a small flexure. Most structures appear to trend north-south to north-northeast, but much local variation was noted. Up to four distinct sets of joints were measured on a single outcrop. In some cases different joint orientations are seen at different stratigraphic levels in the same exposure. The most commonly observed fracture trends are north to south, east to west and N 20° to 30° E.

Weller and Ekblaw (1940) remarked on the abundance of small faults in Union and Alexander Counties, and presented a sketch showing folds and faults in Cincinnatian (upper Ordovician) through Lower Devonian rocks in the Mississippi River bluff near Thebes. They stated, without giving examples, that several of the best exposed faults are obviously thrust faults. This does not coincide with our observations, unless "thrust fault" is defined to include any fracture showing reverse movement.

Many stream valleys in Union and Alexander Counties are remarkably straight. This is especially apparent in the Mill Creek Quadrangle where linear valleys strike N 20° to 40° E, N 60° W, and N 30° W. Straight ravines trending N 20° to 30° W are also prominent in the Wolf Lake and Cobden Quadrangles, while N 20° E streams are noted in the Jonesboro Quadrangle. The significance of these alignments remains to be evaluated. The only linear we could definitely relate to structure is the major stream trending N 20° E in Sections 1 and 12, T 13 S, R 2 W, Jonesboro Quadrangle. This stream followed large and continuous vertical joints striking N 20° E. Other valleys we investigated lacked bedrock exposures, or else available outcrops either lacked joints or showed fractures not parallel with valley walls. Bedrock in the area of straight streams ranges from Bailey Limestone (Lower Devonian) to Springville Shale (lower Valmeyeran).

Whether all of the features described above are of tectonic origin is debatable. Weller and Ekblaw (1940) suggested that many of the small faults and folds might be the product of solution-collapse. Such an explanation is likely for many of the major structures seen in Lower Devonian chert, from which large amounts of carbonate evidently have been leached. Paleo-karst activity accounts less readily for folds and faults in Lingle through Springville clastic rocks because the nearest underlying carbonates are below drainage level. The planar fracture sets and linear valleys are difficult to explain except through tectonic processes.

Summary. The Ste. Genevieve Fault Zone is a narrow, well defined fracture zone that extends from Franklin County, Missouri to Alexander County, Illinois--a distance of roughly 130 miles (200 km). The fault zone lies along the border between the Ozark Dome on the southwest and the Sparta Shelf and Illinois Basin on the northeast.

Two episodes of movement took place. The first was largely confined to Missouri and occurred in late Middle Devonian time. In this episode, the southwestern corner of the Sparta Shelf was uplifted as much as 1,000 feet (300 m) relative to the Ozark Dome. The second larger and more extensive period of movement extended from latest Mississippian through early Pennsylvanian time. The block that was downthrown in the first episode was upthrown in the second. The Ozark Dome was raised as much as 3,250 feet (1,050 m) relative to the Sparta Shelf/Illinois Basin.

The major faults of the second movement are believed to be high-angle reverse or upthrust faults that steepen at depth. Evidence includes rare exposures of actual fault surfaces and widespread overturned strata on the downthrown block of the fault. In Missouri, where sedimentary cover above basement is thin, faulting dominates and little folding has taken place. Southeastward into Illinois, as sedimentary cover thickens, monoclinal folding gradually takes over from faulting as the mechanism of uplift. Large surface faults terminate in Union County, Illinois; but small faults and gentle folds continue southward to the head of the Mississippi Embayment.

Big River Fault System

The Big River Fault System trends southwestward from northeastern St. Francois County to southeastern Washington County, Missouri. It approaches the Ste. Genevieve Fault Zone at its northeastern end; on its southeastern end, it merges with the Palmer Fault System (fig. 2). It cuts upper Cambrian and lower Ordovician strata (Bonneterre through Roubidoux Formations) and its northwestern side is downthrown. Gibbons (1974) measured a vertical separation of 282 feet (86 m) in a roadcut on U.S. Route 67 north of Bonneterre. Maximum throw may approach 400 feet (120 m). In the roadcut, the fault plane of the reverse fault is clean and sharp with no breccia, and it dips 86° southeast. A monocline with a maximum dip of 30° spans the fault. Gibbons also observed small normal faults and breccia zones a few feet wide in a railroad cut near Irondale, where the main fault is not visible.

Gibbons, Tikrity (1968) and McCracken (1971) all indicate that the Big River Fault does not actually join the Ste. Genevieve Fault Zone. The Simms Mountain Fault System approaches the Big River Fault System from the southeast, but the intersection of the two systems has not been observed.

Simms Mountain Fault System and Extensions

The Simms Mountain Fault System (figs. 1 and 2), as shown on McCracken's (1971) map, runs southeastward from the Big River Fault near Irondale to the vicinity of Fredericktown, a distance of about 40 miles (65 km). It thus lies about 15 miles (25 km) southwest of, and strikes parallel with, the Ste. Genevieve Fault Zone. The Simms Mountain Fault System displaces rocks ranging in age from Precambrian to Canadian. The northeast side is downthrown as much as 600 feet (180 m) in places. Observations are scanty, but the faults appear to be nearly vertical (Tikrity, 1968; Gibbons, 1974).

The quadrangles immediately southeast of Fredericktown have never been mapped in detail, so the continuation of the Simms Mountain Fault System in that direction is not known. Mapping by Amos (1982a, 1982b) in the Burfordville and Millersville Quadrangles, however, revealed an extensive system of southeast-trending faults more or less in line with the Simms Mountain Fault System. These are high-angle normal faults having the northeast sides downthrown with displacements ranging from a few tens of feet to about 200 feet (60 m) (Dewey Amos, personal communication, 1984). These faults, in turn, line up with the Jackson Fault and complex southeast-striking fractures mapped by Satterfield (1973) in the Cape Girardeau Quadrangle. Finally, Weller and Ekblaw (1940) illustrated vertical faults and tight folds exposed on the east bank of the Mississippi River just south of Thebes, Illinois.

These findings together strongly suggest a continuous line of high-angle faulting extending from Irondale to the edge of the Mississippi Embayment in Illinois.

Peculiar structures, consisting of narrow downdropped blocks, slices, or fault segments, have been reported from many places along the southeastern part of this fracture zone. Blocks of Ordovician, Silurian, and Lower Devonian (Bailey Limestone) are found surrounded by Canadian or Champlainian strata, as far as 1,000 feet (300 m) below their expected positions. McCracken (1971) reported this situation in the Coal Mine, Glenallen and Marble Hill Faults, Bollinger County, and in the Radio Towner Structure, Cape Girardeau County. Satterfield (1973) mapped many such slices in the Cape Girardeau Quadrangle. Weller and Ekblaw (1940, p. 24) portray downfaulted Silurian and Devonian rocks at Thebes. An excellent exposure of steeply tilted, downdropped strata of Maquoketa Shale through Bailey Limestone (between Kimmswick Limestone on either side) is visible in roadcuts along the Jackson Fault at mile 101.4 on Interstate Highway 55 just north of Cape Girardeau (Thacker and Satterfield, 1977).

Possible explanations for these structures include solution collapse and extensional tectonics. Both the areal extent and the depth of collapse are extremely large for solutionary collapse to have been the cause, but the faults might have acted as channelways for groundwater, which would have created extensive dissolution of carbonates. For the tectonic hypothesis to be valid, there must have been strong tension toward the northeast and southwest, which pulled the walls of vertical fractures apart and allowed slices of rock to drop into the resultant voids.

McCracken (1971, p. 42) reported Cretaceous strata in some of the downdropped areas. These do not necessarily signify post-Cretaceous collapse, because Cretaceous sediments could have been deposited in sinkholes or crevices. The structures are certainly post-Early Devonian. The widespread occurrence of Bailey Limestone in downdropped blocks, but reported absence of any younger bedrock formations, is unexplained.

Farmington Anticline

The Farmington Anticline (fig. 2) is a broad, gentle upwarp situated between the Ste. Genevieve and Simms Mountain Fault Systems and southeast of

the Big River Fault System. Its axis strikes N 30° W and plunges at both ends. Bonneterre Dolomite crops out along the flanks; Lamotte Sandstone is found on the crest, with Precambrian rocks exposed in the deeper stream valleys. The northeast limb dips more steeply (up to 4°) than the southwest limb, which dips only 1° (McCracken, 1971). Closure is roughly 500 feet (150 m), complicated by faulting (Tikrity, 1968).

In its general form and in its relationship to the Ste. Genevieve Fault Zone, the Farmington Anticline resembles the Harrison Creek Anticline in Illinois.

Gibbons (1974) noted that the Farmington Anticline has an almost rectangular outline, rather than the sinusoidal outline typical of compressional folds. He described the fold as having a broad central area of flat-lying strata, bounded by monoclines adjacent to the Ste. Genevieve, Big River and Simms Mountain Fault Zones. These observations led Gibbons to hypothesize that the Farmington Anticline is the surficial expression of faulting in the basement.

Avon Diatremes

Kidwell (1947) reported on 79 igneous dikes and plugs located in southwestern Ste. Genevieve and southeastern St. Francois Counties near the village of Avon (fig. 2). Most are situated on the southern part of the Farmington Anticline. The intrusions vary widely in shape and diameter, from a few feet to about 600 feet (180 m). Kidwell described three kinds of intrusions. Type 1 is composed of aphanitic to porphyritic peridotite or lamprophyre with small inclusions of sedimentary rocks. Type 2, which is the most common of the three types, consists of sedimentary and igneous rock fragments cemented by altered ultramafic rock. Type 3 is rock fragments cemented by carbonate or chlorite and serpentine.

Fragments identified within the diatremes include Precambrian granite, gneiss and schist, and sedimentary rocks ranging from Cambrian to Middle Devonian. Chert in one intrusion contained fossils of Grand Tower Limestone age (Tarr and Keller, 1933). The country rock is Cambrian: Lamotte Sandstone through Potosi Dolomite. Contacts with the wall rocks are sharp, and little or no contact metamorphism is seen.

Kidwell (1947) concluded that the diatremes are the product of explosive igneous activity. Precambrian xenoliths were blasted up from below, while fragments of sedimentary strata, elsewhere eroded today, dropped down the vents or pipes.

Intrusion clearly took place after deposition of the Grand Tower Limestone, as indicated by inclusions of that formation in the diatremes. Zartman et al. (1967) carried out rubidium-strontium and potassium-argon age determinations on biotite from two of the Avon diatremes. Both yielded ages of 396 ± 28 million years: early to middle Devonian. Therefore, the igneous action probably occurred shortly after Grand Tower time, during the first phase of movement on the Ste. Genevieve Fault Zone.

St. Mary's Fault

The St. Mary's Fault (fig. 2) was named by Tikrity (1968), who postulated its existence on the basis of gravity surveys and scanty drill-hole data. No surface exposures have been found. As mapped by Tikrity, the St. Mary's Fault branches northeastward away from the Ste. Genevieve Fault Zone and extends into Randolph County, Illinois. The southeast side is said to be downthrown 200 to 400 feet (60 to 120 m).

We have uncovered no new evidence relative to the St. Marys Fault, and consider its existence questionable.

Cottage Grove Fault System

The Cottage Grove Fault System (fig. 1) crosses southern Illinois in an east-west direction and is at least 70 miles (113 km) long. Nelson and Krause (1981) described the system in detail and, in agreement with earlier workers, proclaimed it to be a right-lateral strike-slip fault. The main east-west fault has up to 200 feet (60 m) of vertical separation and the direction of downthrow is inconsistent. Horizontal displacement is unknown but certainly less than one mile (1.6 km) and probably not much over 1,000 feet (300 m). Numerous secondary northwest-trending faults are predominantly high-angle normal, but some show horizontal offset. Associated with the fault zone is a belt of en echelon anticlines, of which the Campbell Hill Anticline in western Jackson County is the most prominent example (fig. 2).

The faults displace middle Pennsylvanian strata, and some contain peridotite dikes radiometrically dated as early Permian (Nelson and Lumm, 1984). The time of faulting, therefore, is somewhat younger than that of the Ste. Genevieve Fault Zone.

Heyl (1972) and others have speculated that the Cottage Grove Fault System connects the Ste. Genevieve Fault Zone with the Rough Creek Fault System in western Kentucky. The St. Mary's Fault, if it exists, might provide the western link. For its part, the Cottage Grove Fault System cannot be positively traced west of the Campbell Hill Anticline. Outcrops and subsurface information are rare in eastern Randolph County, but exposures along the Mississippi River bluffs are good, and afford no sign of faulting. We therefore regard a connection between the Cottage Grove and Ste. Genevieve Fault Zones as unlikely.

Bodenschatz-Lick Fault

Flint (1925) mapped the Bodenschatz-Lick Fault southwest of the Ste. Genevieve Fault Zone in the Altenburg Quadrangle, Missouri (fig. 2). The fault trends northeast and has the southeast side downthrown; it intersects the Ste. Genevieve Fault Zone in the northeast. The fault trace follows stream valleys and is mainly concealed by alluvium, but is indicated by differences in altitude of nearby outcrops. Dewey Amos (personal communication, 1984), in remapping the Altenburg Quadrangle, confirmed the existence of the Bodenschatz-Lick Fault mapped by Flint.

Subsurface data indicate that the Bodenschatz-Lick Fault crosses the Ste. Genevieve Fault Zone and extends into Jackson County, Illinois. Contouring on the Beech Creek ("Barlow") Limestone (Chesterian) reveals approximately 600 feet (180 m) of downthrow to the southeast, probably on more than one fault. The fault zone trends N 35° E for about 17 miles (27 km) northeast of the Ste. Genevieve Fault Zone, then it dies out into a flexure and curves eastward, approaching the Cottage Grove Fault System.

The displacement appears to increase downward and diminish upward. Limited data on the New Albany Shale (Upper Devonian) suggest 200 to 300 feet (60 to 90 m) more offset on that horizon than on the Beech Creek Limestone. Part of the apparent increased offset, however, may reflect eastward thickening of the strata between the Beech Creek and New Albany. Pennsylvanian strata, on the other hand, apparently are not faulted at all, but only gently folded across the Bodenschatz-Lick structure. Shaw's (1910) structure map of the Murphysboro Coal Member of the Spoon Formation shows a monocline having 200 to 400 feet (60 to 120 m) of stepdown to the east. In surface mapping, he found no dips steeper than about 10° on the flexure. Kolesar (1964) likewise found no evidence of surface faulting or steep dips during quadrangle mapping along the trace of the subsurface Bodenschatz-Lick Fault. We field-checked the area ourselves and confirmed the results of earlier studies. The steepest dips, 12° to 14°, were measured on sandstones of the Caseyville Formation; and this was somewhat questionable due to crossbedding. Some outcrops displayed moderate jointing, with the preferred trends N 5° W to N 20° E and N 55° to 65° E. These two sets roughly form a conjugate pattern, about 30° either side of the trend of the buried fault. Outcrop exposures admittedly are sporadic, but it appears safe to conclude that uplift across the Bodenschatz-Lick structure is less in Pennsylvanian than in Mississippian and Devonian strata, and that no large faults reach the surface in Illinois.

Two wells in Missouri opposite Fountain Bluff apparently penetrated segments of the Bodenschatz-Lick Fault. In one well (NE, Section 6, T 34 N, R 14 E) approximately 320 feet (96 m) of section, including the Kimmswick Limestone and part of the Maquoketa Shale Group (Ordovician) were missing. The other well, in Section 1, T 34 N, R 13 E, may have cut two faults. One removed the New Albany Shale Group and part of adjacent formations while the other took out some of the Lower Devonian strata. The slice of rock between the two faults was abnormally thickened, suggesting that it is steeply tilted.

In summary, the Bodenschatz-Lick Fault crosses the Ste. Genevieve Fault Zone at a right angle. Displacement is down to the southeast along a series of normal faults. The throw appears to decrease upward, and the fault may pass upward and northeastward into a flexure. At least part of the movement is post-Murphysboro Coal, and therefore somewhat younger than the Ste. Genevieve Fault Zone.

Cap au Gres Faulted Flexure

Although it does not link structurally with the Ste. Genevieve Fault Zone, the Cap au Gres Faulted Flexure (fig. 1) merits discussion because its form and history are similar to those of the Ste. Genevieve Fault Zone.

The Cap au Gres structure trends east-southeast from Pike County, Missouri to northwestern Madison County, Illinois, a distance of roughly 60 miles (100 km). It is a very sharp monocline with the south side downwarped. Dips greater than 5° occur in a zone only 1,000 to 1,500 feet (300 to 400 m) wide. Steepest dips on the limb of the flexure range from about 65° southward to vertical or even overturned (65° north). Discontinuous faults parallel to strike are present and generally cut the fold north of the axial plane. Their displacements do not amount to more than one third of the total structural relief. Fault planes dip steeply; some are observed to be nearly vertical. Geometric configurations suggest that the larger ones are high-angle reverse faults with the northern sides upthrown (Rubey, 1952).

The history of deformation is long. Tikrity (1968) cites stratigraphic evidence for uplift west and southwest of the present flexure, commencing in late middle Devonian time and continuing into the Kinderhookian Epoch. His evidence includes

1. westward thinning of Upper Devonian and Kinderhookian units;

2. angular unconformities beneath these units, with progressively more sections missing westward;

3. presence of sand and conglomerate in certain Upper Devonian-lower-Mississippian units.

Additional movements took place during Valmeyeran time. The major uplift, which produced the faulted flexure, occurred after deposition of the St. Louis Limestone and before Pennsylvanian sedimentation. It cannot be more precisely dated because the Ste. Genevieve Limestone and Chesterian Series are not present in the region. This movement reversed the earlier and more widespread Devonian-Kinderhookian uplift.

Later down-to-the-south movements tilted and displaced Pennsylvanian (Spoon and Carbondale Formations) strata along the faulted flexure. These offsets were much smaller in magnitude than the main pre-Pennsylvanian uplift. Yet another episode of uplift took place in late Tertiary time. The Grover Gravel of Miocene (Rubey) or Pliocene (Treworgy, 1979) age, and its underlying peneplain are found approximately 150 feet (45 m) lower south of the flexure than to the north (Treworgy). The overlying Pleistocene loess, however, shows no indication of tectonic disturbance.

This history is much like that of the Ste. Genevieve Fault Zone: late Devonian uplift, reversed by major late Mississippian-early Pennsylvanian uplift, with minor subsequent rejuvenation.

The origin of the Cap au Gres Faulted Flexure has inspired debate. Rubey (1952), whose geometric and mechanical analysis was extremely thorough, ruled out the possibility that the fold represents drag on normal (tensional) faults. He favored horizontal compression from the north that warped the strata upward and broke them locally. He regarded as almost equally plausible the possibility of deep-seated reverse (upthrust) faulting of the basement, that did not everywhere break through to the surface. Tikrity (1968) favored the latter hypothesis, citing gravitational and magnetic surveys. Cole (1961), however, proposed that the Cap au Gres structure underwent 30 miles (50 km) of

left-lateral strike-slip movement, offsetting a formerly continuous anticlinal trend. This theory found few supporters, and was refuted at length by Tikrity. Treworgy (1979) did not take a stand.

In our opinion, the geologic data plus regional considerations favor the hypothesis of vertical upthrusting of a basement block. The hypothesis is supported by the following facts: (1) the attitudes of faults and the flexural plane are steep (nearly vertical), (2) the deformed zone is narrow but intense, (3) there are locally overturned strata, and (4) there is evidence of reverse faulting. By contrast, horizontal compression should result in low-angle thrust faults and/or belts of parallel folds. Cole's strike-slip hypothesis appears untenable also because it is difficult to conceive of such a huge horizontal offset on so short a fault zone.

• Waterloo-Dupo Anticline

The Waterloo-Dupo Anticline (fig. 1) is another structure that does not link with the Ste. Genevieve Fault Zone, but shows similar geometry and time of movement.

The anticline strikes slightly west of north from Monroe County, Illinois, through St. Louis, Missouri, to the south side of the Cap au Gres Faulted Flexure. It consists of three elongate domes in a line, separated by low saddles. The fold is strongly asymmetrical: the western flank is steep; the eastern flank, gentle. We have observed dips steeper than 45° on the western flank, while on the eastern flank dips range from 2° to 4°. Lamar (1922) and Weller and Weller (1939) both stated that the steep western limb of the anticline is faulted in Illinois. Lamar reported that the fault is normal, bringing steeply dipping Warsaw Limestone on the east against gently dipping Chesterian strata on the west. Creviced rock and crystalline quartz were encountered in a well that penetrated the fault, according to Lamar.

Two periods of movement are indicated. They are the same as those inferred for the Ste. Genevieve Fault Zone. The first was post-middle Devonian, pre-Mississippian. It is indicated by subsurface thinning of the Silurian and Devonian strata across the crest of the fold. The vertical uplift during this phase was 90 to 120 feet (30 to 40 m) (Tikrity, 1968). The second (major) episode of folding took place in late Mississippian or early Pennsylvanian time. This movement is evidenced by angular unconformity between Mississippian and Pennsylvanian strata on the western limb of the fold. We were able to dig a clean exposure of the unconformity out of the bank of the west-flowing stream, just east of the railroad trestle in the NE NW NE, Section 3, T 2 S, R 10 W, Monroe County, Illinois. In this exposure lower Chesterian limestone, dipping 40° to 50° west, was overlain by Desmoinesian (middle Pennsylvanian) coal and underclay dipping approximately 10° west. About 200 feet west, near the railroad trestle, the Pennsylvanian strata are horizontal. The gentle tilt of the coal and underclay above the Chesterian rocks signifies a slight post-Desmoinesian uplift.

The geometry of the Waterloo-Dupo Anticline suggests that a basement block was raised and gently tilted eastward along a vertical or steeply dipping fault.

GEOPHYSICAL STUDIES

Gravity Surveys

The earliest gravity survey of interest is that of Segar (1965). His investigation covered most of Perry and Ste. Genevieve Counties, Missouri, and Randolph, Jackson, and Union Counties, Illinois; and parts of adjacent counties. Thus, Segar's survey included most of the Ste. Genevieve Fault Zone.

The largest, most obvious feature on Segar's gravity map is an elongate high with up to 30 milligals of relief trending southeastward from Perry County, Missouri, to Union County, Illinois. The anomaly is asymmetrical, with a much sharper gradient on the northeastern than on the southwestern margin. The northeastern gradient closely corresponds with the Ste. Genevieve Fault Zone. The surface trace of the fault follows the bottom of the rise in gravity values. Segar attributed this feature to dense basement rock on the upthrown side of the Ste. Genevieve Fault Zone.

Just southwest of Jonesboro, Illinois, a small gravity low lies northeast of a small high. Segar correlated this to the Atwood Fault, which strikes N 15° W and has the southwest (high gravity) side upthrown.

A prominent gravity low extends east-northeast from the vicinity of Ste. Genevieve, Missouri, to Sparta, Illinois. Segar had no theory on the significance of this anomaly, which lies north of and trends parallel with the westward projection of the Cottage Grove Fault System.

McGinnis et al. (1976) reported on the gravity field and tectonics of Illinois. Their maps show the highest Bouguer and free-air gravity beneath the Mississippi Embayment at the southern tip of the state. Since the sedimentary section, composed of relatively light rocks, is thickest in the Embayment, the lower crust and/or upper mantle must contain denser rock than elsewhere to account for the high gravity. The high free-air gravity in the Embayment indicates the region has not reached isostatic equilibrium. McGinnis et al. (1976) proposed that either the Embayment is subsiding and the free-air gravity field is being diminished or that the free-air gravity field is being maintained by active contemporary tectonic stress.

The sharp gradient along the Ste. Genevieve Fault Zone appears much the same on both the McGinnis et al. map and the Segar maps. The gradient abruptly decreases at Bald Knob where large surface faults terminate. A weaker slope continues south-southeastward through Alexander County, Illinois, corresponding with the gently dipping extension of the Rattlesnake Ferry monocline. McGinnis et al. modeled the 20-milligal Bouguer gravity high in central Alexander County, west of the monocline. The model produced is a plug-like body of dense rock about 2 miles (9.7 km) in diameter within the upper crust. This body has an inferred density of 3.1 to 3.2 gm/cc, about 0.40 gm/cc denser than surrounding rock. Its top is about 5 miles (8 km) below the surface, well into the crystalline basement.

The gravity low of Randolph County, Illinois, was also modeled. The calculations indicated a mass of material about 0.06 gm/cc less dense than

surrounding rock, and reaching within 1 mile (1.6 km) of the surface, which is roughly the depth to basement here.

Gravity maps of Hildenbrand et al. (1977) cover most of the Ste. Genevieve Fault Zone except for the northwesternmost portion. The Bouguer gravity map for Illinois is essentially similar to that of McGinnis et al. (1976). In Missouri, Hildenbrand et al. (1977) show a strong gravity low near Weingarten, where the fault zone bends from east-west to northwest-southeast. Unfortunately, this lies at the edge of the map. A paired low/high, with long axis trending northwest, is mapped along the Illinois-Kentucky border beneath the Mississippi Embayment. Hildenbrand et al. postulated that this reflects a southeastward extension of the Ste. Genevieve Fault Zone. Such an extension would cross the Reelfoot Rift at nearly a right angle.

A series of gravity surveys were run specifically for our study with the aim of locating the buried southward extension of the the Ste. Genevieve Fault Zone. Mitchell Coe, under the direction of Dr. Lawrence L. Malinconico, both of Southern Illinois University at Carbondale, conducted the study. A Worden gravimeter was used, and 1.6 to 8 stations per mile (1 to 5 per km) were occupied along 10 traverses covering a total distance of 175 miles (280 km).

Coe's gravity profiles 1 and 2 cross the Rattlesnake Ferry Fault where its surface displacement is large (fig. 26). Both profiles show a strong gravity gradient corresponding with the fault zone. High gravity values southwest of the fault zone indicate that dense basement rock is uplifted there. Profile 3, which begins just north of the Rattlesnake Ferry Fault and extends northward, shows high gravity values to the south, decreasing northward. The high to the south may reflect proximity of the basement block uplifted along the Rattlesnake Ferry Fault and/or a buried extension of the Pomona Fault.

Profile 4-5 extends roughly east-west through the village of Anna, south of the surface termination of the Rattlesnake Ferry Fault. This line crosses the Harrison Creek Anticline and the Atwood Fault. An irregular eastward drop in gravity values is shown. East of Anna, the values become nearly constant. A similar pattern is shown on Profile 5, south of Profile 45: two pronounced peaks correspond approximately with the Harrison Creek Anticline and Atwood Fault. The anomalies are much sharper than one would expect from the modest surficial expression of the anticline and fault. Thus, the gravity data strengthen our contention that the Harrison Creek Anticline and Atwood Fault are controlled by larger faults at depth.

Coe's Profiles 6, 7, and 8, farther south, were carried eastward to intersect the proposed southernmost extension of the the Ste. Genevieve Fault Zone (Hildenbrand et. al. 1977). Coe's gravity lines show a gentle eastward drop in gravity values, but no sharp anomalies, such as appear in Profiles 1 to 5. Therefore, it is unlikely that any large faults occur within the span of these profiles.

In summary, Coe's new gravity data support our conclusion, based on geologic evidence, that the the Ste. Genevieve Fault Zone is the surface

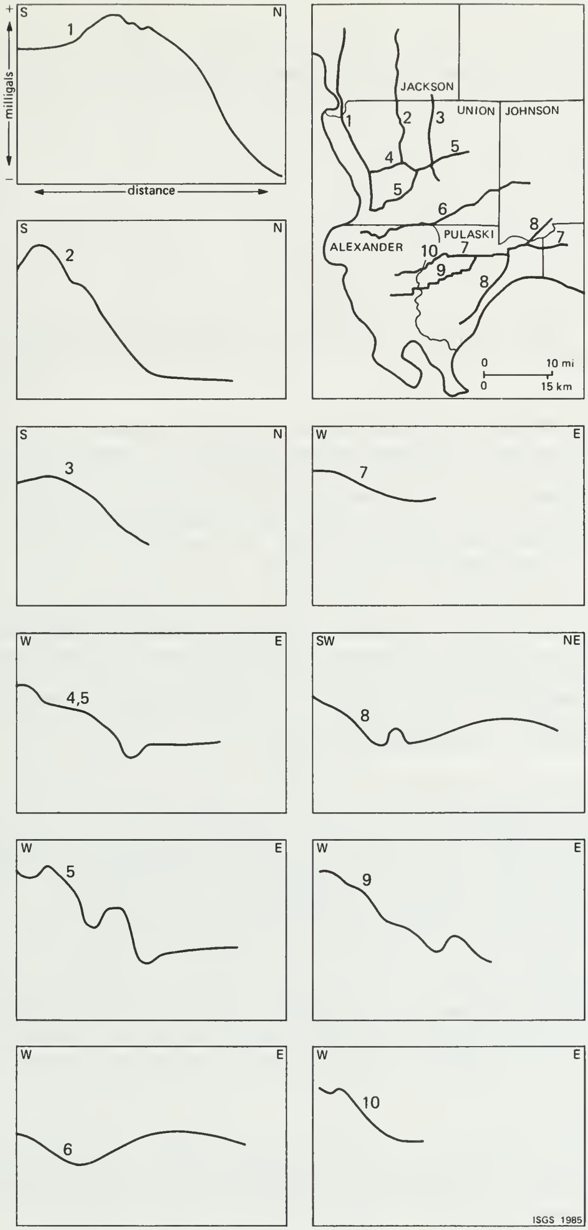


Figure 26 Gravity profiles in southwestern Illinois (from Coe, 1985).

expression of large-scale uplift of the crystalline basement. The basement fault zone curves southward in northern Union County and splits into two or more branches which die out upward through the sedimentary column.

Magnetic Surveys

The magnetic map of Segar (1965) shows no anomalies attributable to known structure along the Ste. Genevieve Fault Zone. The most prominent feature on the map is a sharp gradient with a relief of 200 gammas or more, but lower to the south. It trends N 75° W from northwestern Jackson County, Illinois, to the Mississippi River. This corresponds with the large gravity low mentioned above, and also lines up with the westward projection of the Cottage Grove Fault System. Segar interprets the cause of the anomaly as either a fault or change of lithology in the basement at a depth of 13,500 feet (4100 m) or more.

Heigold's (1976) aeromagnetic map shows the same gradient and traces it farther east. From Jackson County to Hardin County, Illinois, the magnetic slope runs parallel with the Cottage Grove Fault System but is roughly 10 miles (16 km) south of the fault zone. Heigold speculated that the gradient may represent the ancestral Cottage Grove Fault (Rough Creek Graben) and that positive anomalies aligned with, and north of, the gradient possibly indicate igneous rocks intruded along the fault zone.

A large positive anomaly in northwestern Union County, Illinois, corresponds with the upthrown block of the Ste. Genevieve Fault Zone. A second, even sharper high in Alexander County, Illinois, matches the gravity maximum described above and strengthens the theory that a large mafic igneous mass occurs in basement in that location. The Union County anomaly also may be a basic intrusion, or alternatively, may merely reflect uplift of the basement along the Ste. Genevieve Fault Zone.

The digital magnetic-anomaly map of the central United States by Hildenbrand et al. (1983) shows a belt of strong negative anomalies roughly coinciding with the Ste. Genevieve Fault Zone and extending southeastward across the Reelfoot Rift into Tennessee. Hildenbrand et al. inferred that the fault zone itself follows the magnetic lineament into Tennessee. Their hypothesis does not take anything but magnetic data into account. It does not attempt to explain why the Ste. Genevieve Fault Zone should produce a negative anomaly. The map actually shows a southward curve in the magnetic low in southernmost Illinois, making southward extension of the fault equally plausible with the southeastward lineament. Furthermore, this map shows that many large faults (e.g., the Rough Creek-Shawneetown Fault System) do not produce magnetic lineaments and that many strong magnetic anomalies in Illinois and elsewhere cannot be correlated with any known structure.

Seismic Surveys

We are unaware of any commercially produced seismic profiles for the Ste. Genevieve Fault Zone. If any have been run, the results have not been released to the public.

In the summer 1981, Paul C. Heigold of the Illinois State Geological Survey, attempted to obtain reflection seismographic profiles across the Rattlesnake Ferry Fault and monocline in Union County, Illinois. No meaningful data were acquired. Failure was attributed to the weak energy source (small dynamite charges), dispersal of energy by deep alluvial and residual soils, interference produced by waves reflecting off the walls of deep narrow bedrock valleys, and lack of suitable velocity contrasts in near-surface strata.

TECTONIC ANALYSIS

Origin of Ste. Genevieve Fault Zone

- **Devonian faulting**

The earliest movements in the Ste. Genevieve Fault System took place in late Middle Devonian time. This faulting produced uplift on the north: the Sparta Shelf was raised relative to the Ozark Dome (fig. 27). Maximum vertical separation was approximately 1,000 feet (300 m) in Ste. Genevieve County, Missouri. The Devonian faulting diminished eastward and terminated in Randolph County, Illinois. Westward, the fractures ended close to the Ste. Genevieve-St. Francois county line. Devonian slippage took place on faults that lie along the northern margin of the present Ste. Genevieve Fault Zone.

Devonian faulting is demonstrated by the major sub-Mississippian or sub-New Albany unconformity north of the fault zone. It is further shown by the abundance of locally derived clastic sediment in upper Middle Devonian strata (Beauvais Sandstone, St. Laurent, Alto and Lingle Formations) just south of the zone. This detritus was reworked from upper Ordovician, Silurian and Devonian formations eroded from the uplifted Sparta Shelf. Also, the Avon diatremes have been dated as middle Devonian.

The structural nature of the Devonian faults is poorly known. They are buried by younger sediments over large areas. The few exposed faults are described as steep normal fractures, but these may not be the main faults. No evidence for thrust faulting or strike-slip movement is apparent. Therefore, it seems best to characterize these Devonian structures as high-angle, dip-slip faults. A more or less vertical uplift of the Sparta Shelf, possibly with a tensional component of movement, is indicated.

The Sparta Shelf was the active member. It was lifted and exposed to subaerial erosion, whereas the region to the south remained a shallow sea, at least through the time of deposition of the Lingle Formation (North, 1969a, 1969b). Deep-water sediments in the Upper Devonian reflect general subsidence of the entire region as the Ste. Genevieve Fault Zone became quiescent.

The Sparta Shelf tilted toward the northeast. Its southwestern corner, near Weingarten and Ozora, rose the most, while its southeastern and northwestern corners acted as hinges. The northeastern corner of the shelf, along the site of the Cap au Grès Faulted Flexure, apparently rocked downward, as evidenced by unconformities and facies changes in Devonian and

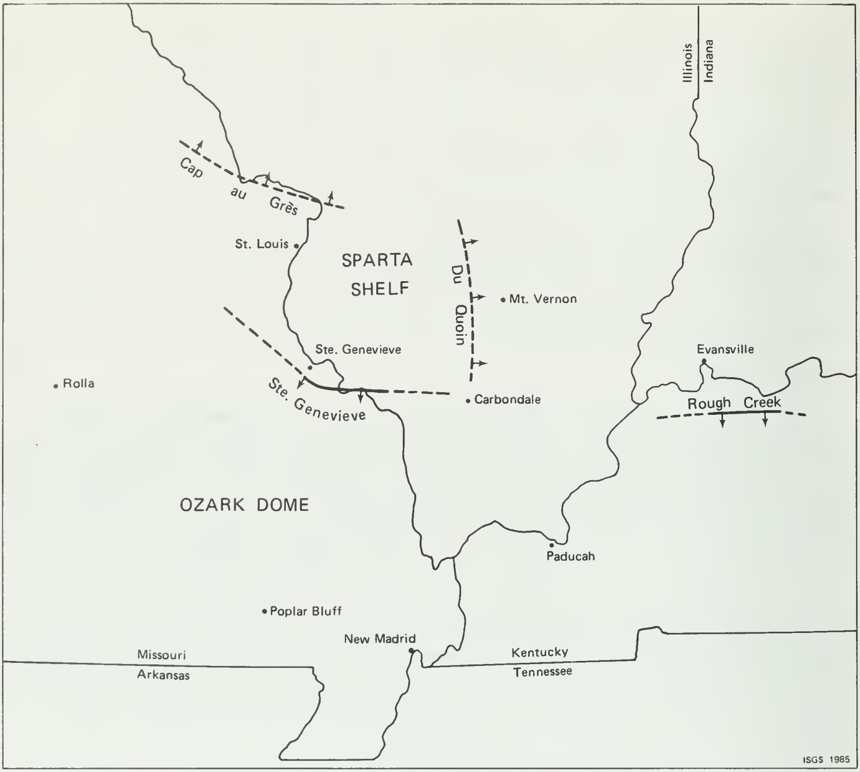


Figure 27
Schematic map of tectonic activity in late Middle Devonian time. The Sparta Shelf was raised, with the uplift greatest at the southwest corner. Southwest of Ste. Genevieve, Devonian faults have maximum vertical offset of roughly 1,000 ft (300 m) and die out both eastward and westward. This tilting of the Sparta Shelf produced eastward and northeastward flexure along the lines of what was to become the Du Quoin Monocline and Cap au Gres Faulted Flexure, respectively. The only other recorded movement in the region was a mild uplift along the eastern segment of the Rough Creek Fault System in Kentucky.

Kinderhookian strata (Tikrity, 1968). The Sparta Shelf remained intact, moving essentially as a block of the earth's crust. Ultramafic (mantle-derived) material in the Avon diatremes points to the deep-seated nature of the disturbance.

We are not ready to speculate on the tectonic processes that tilted the Sparta Shelf. The only other place in the region where middle to late Devonian faulting is documented is along the eastern part of the Rough Creek Fault System, Kentucky. Stratigraphic relationships there indicate moderate uplift of the north side of the fault zone. The closest major tectonic activity was in New England, where the Acadian Orogeny was getting under way.

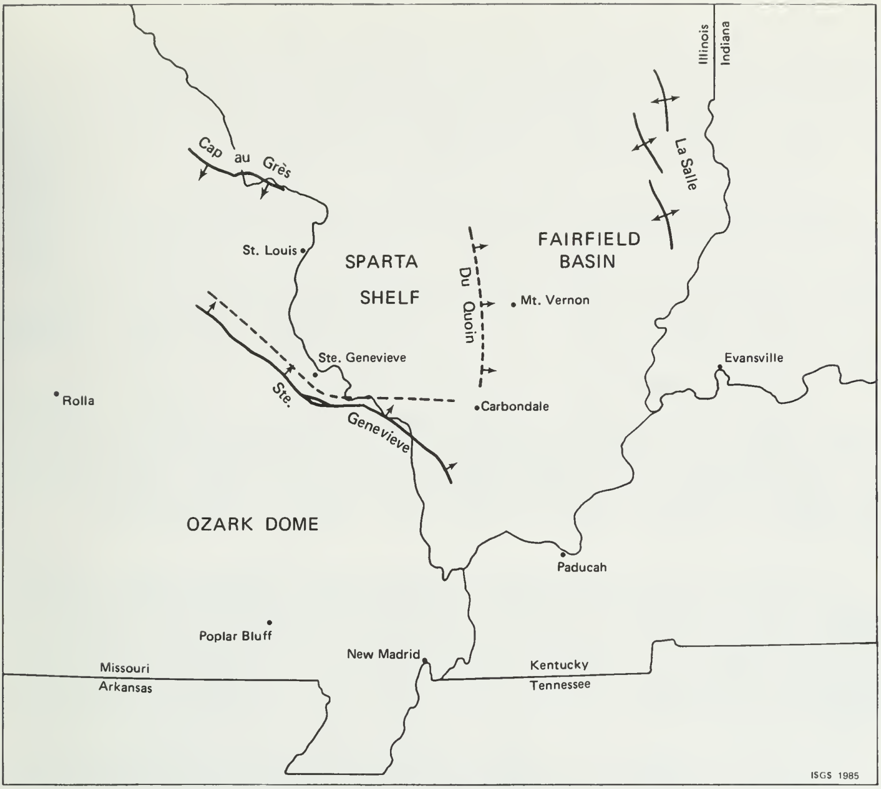


Figure 28
Schematic map of tectonic activity in late Mississippian-early Pennsylvanian time. Ozark Dome was uplifted relative to the Sparta Shelf along the Ste. Genevieve Fault Zone. The new faults were immediately southwest of the Devonian ones, which are indicated by dashed line. The northwestern corner of the Sparta Shelf also sank along the Cap au Gres Faulted Flexure, but the eastern margin of the shelf may have risen slightly along the Du Quoin Monocline. The other major development at this time was the appearance of the La Salle Anticlinal Belt in eastern Illinois.

• Mississippian-Pennsylvanian faulting

The second major period of tectonic activity in the Ste. Genevieve Fault Zone took place in latest Mississippian and early Pennsylvanian time. This activity reversed the earlier Devonian faulting, uplifting the Ozark Dome relative to the Sparta Shelf and Illinois Basin. The Ozark block rose more than 3,000 feet (900 m) in places along pre-existing fractures. The later faults developed mostly southwest of the Devonian faults and extended beyond the Devonian fault zone at both ends (fig. 28).

Field observations along the deformed zone in Illinois were the basis for our determinations of the time during which faulting occurred. Chesterian and

older rocks within the zone have been considerably folded and faulted. Superjacent lower Pennsylvanian rocks show only gentle tilting and minor faulting. Pennsylvanian faults visibly die out upwards within outcrops, and many show evidence of having formed before the sediments became lithified. Chert conglomerates and paleocurrent analysis indicate that a prominent fault scarp existed during deposition of the Caseyville Formation.

The master fault of the Carboniferous portion of the Ste. Genevieve Zone is a steeply inclined reverse fault with its southern or southwestern side upthrown. Coinciding is a sharp monoclinal flexure with the same direction of throw. The fault trace lies immediately southwest of the flexural hinge and typically shows vertical or overturned strata; rotation is as much as 145°. The beds on the upper and lower limbs of the monocline are horizontal or gently dipping. Smaller faults in the Ste. Genevieve Fault Zone trend parallel, oblique, or normal to the master reverse fault. These smaller faults appear to be mostly vertical or steep normal faults.

The master fault apparently steepens downward, becoming almost vertical. This was directly observed at Weingarten and Red Rocks Landing. This is also supported by the fact that as the sedimentary cover above Precambrian basement thickens, the angle of the fault decreases eastward. This suggests a general flattening of the fault upward in the sedimentary column (Gibbons, 1974).

We obtained relatively good data for the the Ste. Genevieve Fault Zone at 13 locations (table 1). Information includes approximate width of the main deformed zone, total vertical uplift, amount and percentage of uplift due to faulting (as opposed to folding), depth to basement on the upthrown block, and maximum observed dip of strata in the fault zone. Locations are listed beginning at the northwest and proceeding toward the southeastern terminus of surface deformation.

The depth to basement increases southeastward along the fault zone (table 1). Corresponding with the southeastward increase in sedimentary cover is a general widening of the deformed zone and decrease in the magnitude of faulting versus folding. In Missouri, where sedimentary cover above basement is thin, the deformed zone is less than 3000 feet (900 m) wide; faulting generally accounts for more than half of the total stratigraphic offset. In Illinois, however, the zone becomes much wider as faulting dies out into a monoclinal flexure. Total uplift is greatest near the center of the system and diminishes toward the two ends. Total uplift changes gradually, but other parameters vary widely within short distances. For example, approximately 45 percent of offset at Rattlesnake Ferry is due to faulting, but 1/2 mile (0.8 km) to the southeast faulting accounts for about 70 percent of the overall uplift. The actual amount of vertical uplift is the same at both locations.

These data suggest that faulting originated in the basement and died out upward through the sedimentary cover. The basement may have been essentially rigid, thus was offset by a large, nearly vertical block fault. Sedimentary strata, which were draped across the fault, responded passively. Stearns (1978) describes the process as "forced folding." The deeper strata are sheared along with the basement, but upward the displacement is gradually

accommodated by folding, flexural slip, flow, and small-scale fracturing. The limb of the "forced fold" is stretched as the fold develops. Weak units, especially shales, may flow under tension, but rigid beds are fractured. The numerous small normal faults observed at Vineland, Valles Mines, Interstate 55, and elsewhere may be examples of tensional fractures produced in this manner. Even clearer examples are the wide calcite-filled fractures seen in Union County, Illinois (fig. 22); the walls of the latter fractures were pulled apart laterally, and the fractures overlie and line up with the limb of the Rattlesnake Ferry monocline, beyond the apparent southeastern terminus of surface faulting.

The little reverse fault-flexure observed in the railroad cut at Vineland Crossing (fig. 12) may represent a small-scale version of the main Ste. Genevieve fault, as it dies out upward.

We believe that vertical uplift of the Ozark block, rather than horizontal compression, produced the the Ste. Genevieve Fault Zone. Both laboratory simulations (Sanford, 1959) and field observations in other regions (Kerr and Christie, 1965; Stearns, 1978; Swenson, 1984) show that direct uplift produces a structure similar to the Ste. Genevieve. Cross sections from the Laramie Range, Wyoming (fig. 29; Swenson, 1984), show the Precambrian

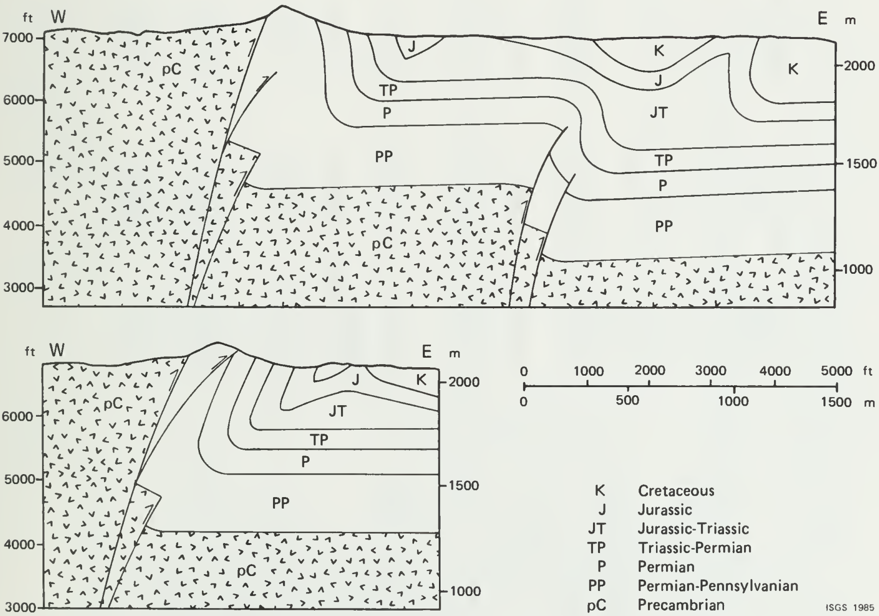


Figure 29
Cross sections of the Laramie Range, Wyoming, illustrating upthrusting of basement blocks. No vertical exaggeration. (Drawings provided by Alan Swenson, 1984.)

Table 1. Dimensions of Ste. Genevieve Fault Zone at selected localities

Location	A. Width ft/m	B. Total offset ft/m	C. Fault offset ft/m	D. Fault offset %	E. Basement depth ft/m	F. Maximum dip ft/m
Vineland Crossing Jefferson Co., MO	2500/760	1300/400	650/200*	50	800/250	90*
Valles Mines Jefferson Co., MO	2500/760	1000/300	650/200*	65	1200/370	45*
Weingarten Ste. Genevieve Co., MO	500/150	2000/600	1000/600*	50	200/60	45?
I-55 roadcuts Ste. Genevieve Co., MO	3000/900	2000/600	1800/550	90	3000/900	137
McBride Perry Co., MO	2000+/600+	3250/1050	3000/900	90	3000/900	135
Red Rocks Landing Perry Co., MO	2000+/600+	3800/1080	1600/490	42	3200/975	145
Grand Tower Jackson Co., IL	9000/2750	2900/880	800/245	28	4300/1310	25
Rattlesnake Ferry Jackson Co., IL	5000/1500	2900/880	1300/400	45	4300/1310	100
1/2 mile SE of Rattlesnake Ferry Jackson Co., IL	2500/750	2900/880	2050/625	70	4300/1310	120
Bald Knob Union Co., IL	2000/600	2400/730	1300/425	55	4900/1490+	45

Table 1. Continued

Location	A. Width ft/m	B. Total offset ft/m	C. Fault offset ft/m	D. Fault offset %	E. Basement depth ft/m	F. Maximum dip ft/m
Clear Creek Union Co., IL	5000/1500	2300/700	250/75	11	5200/1580+	35
Iron Mountain Union Co., IL	7500/2300	1750/535	0?	0?	5500/1680+	18
Jonesboro Union Co., IL	10,000-20,000/ 3000-5000	1500/460	0	0	5500/1680+	5

*Data from Gibbons, 1974.

A. Width of deformed zone. Includes all large faults and monoclinal flexure, generally with dips of 5° or more. Does not include faults and folds outside main zone, or faulting of Devonian age.

B. Total vertical stratigraphic offset across deformed zone. This figure should reflect the amount of uplift of the Precambrian surface.

C. Vertical stratigraphic offset due to observed and inferred faults. These are minimum figures in most cases. Where strata are steeply dipping and/or fault planes deviate much from vertical, net slip may be considerably greater than figures given here.

D. Percentage of total offset due to faulting, rather than folding (C/B).

E. Inferred depth to top of Precambrian rocks on upthrown side of deformed zone. This figure calculated from average thicknesses of strata as shown in figure 5. In Union County, Illinois, several thousand feet probably can be added to these figures to allow for thickened Cambro-Ordovician section in Reelfoot Rift.

F. Maximum dip of bedding observed in deformed zone. Figures greater than 90° signify overturned bedding.

basement upthrown along a series of reverse faults that steepen downward and die out upward through the sedimentary section. The basement was essentially rigid and underwent little folding, but sharp flexures developed upward in sedimentary strata. Stresses also were relieved by flexural slip along bedding planes and (in this case) by plastic deformation of Triassic and Jurassic evaporites.

Horizontal compression, on the other hand, produces thrust faults that flatten with depth, often becoming horizontal detachments or dêcollements. Such structures are well documented in the Appalachian orogenic belt. The Pine Mountain Overthrust is a prime example. Some detachment faults now are known to extend many tens of miles northwest of the Allegheny Front, through the flat-lying strata of the foreland plateau (cf. Burning Springs Anticline of West Virginia; Woodward, 1959; Rodgers, 1963; and Gwinn, 1964). But these thrusts are entirely within the sedimentary column and do not cut basement. To the east, in the Blue Ridge Province (the line of continental collision), thrust faults extend into the crystalline rocks (Boyer and Elliott, 1982).

Hamilton (1981), citing evidence from seismic surveys and deep boreholes, indicated that many of the great Laramide faults bordering mountain ranges in the Southern and Middle Rocky Mountain Provinces, which were previously interpreted as near-vertical upthrusts, actually flatten at depth and become low-angle thrusts. These findings implicate horizontal compression in the origin of those faults. Hamilton suggested that compression was caused by rotation of the entire Colorado Plateau Province; the rotation was induced by oblique convergence of lithospheric plates to the west. His hypothesis, however, appears inapplicable to the Ste. Genevieve Fault Zone. Not only is the field evidence contrary, but also, the only plausible source of the initiating compression would be the Ouachita belt. In late Mississippian-early Pennsylvanian time, however, this was a rapidly subsiding geosynclinal trough, receiving tens of thousands of feet of clastic sediment. Convergence and thrusting did not commence until post-Atokan time (Haley et al., 1979; Fay et al., 1979), well after creation of the Ste. Genevieve Fault Zone.

Strike-slip origin of the Ste. Genevieve Fault Zone has been suggested by some geologists. Heyl (1972) cited horizontal slickensides, and Olsson (1968) cited fracture patterns as supporting evidence. Nevertheless, the idea of major wrench faulting fails to account for the consistent southwestern uplift and consistent orientation of fault plane and monocline. Secondary drag-folds and flexures have horizontal and parallel axes, indicating dip slip. The few slickensides we observed are vertical or nearly so, with rare exceptions in intensely deformed areas. Such features as "flower structures" or pop-up blocks, reversals in throw of faults, en echelon anticlines, and pinnate normal faults, which characterize wrench faulting, are missing. The fault zone bends sharply along strike, which is not characteristic of strike-slip fault. True wrench faults branch or splinter where they curve along strike (Nelson and Krausse, 1981).

We cannot rule out a small amount of lateral slippage. The fracture pattern along the Pomona Fault suggests a component of strike slip. We are convinced, however, that the main motion was vertical or dip slip.

Vertical block faulting of the basement appears to be a common structural style in the Ozark region and Illinois Basin. Although small strike-slip faults have been documented, vertical upthrusting is dominant in the central Ozarks (Tikrity, 1968; Gibbons, 1974). The Cap au Gres Faulted Flexure probably resulted from direct uplift. The Rough Creek-Shawneetown Fault System probably was created by vertical lifting of the southern block, followed by subsidence to approximately its original elevation (Nelson and Lumm, 1984).

In late Mississippian-early Pennsylvanian time, tectonic activities affected many Midcontinent structures, including the Ste. Genevieve Fault Zone. The main development of the Cap au Gres Flexure (Rubey, 1952), as well as much of the folding in the LaSalle Anticlinal Belt (Clegg, 1965), took place at that time. Moreover, the entire Illinois Basin area emerged, tilted southwestward, and then was scoured by Pennsylvanian rivers (Bristol and Howard, 1971 and 1972). Intense tectonic activity occurred farther west in the Midcontinent at the same time. The Cambridge Arch, Central Kansas Uplift, Mississippi River Arch, Lincoln Fold, Saline Basin, Nemaha Ridge, and Forest City Basin all are believed to date from Chesterian or earliest Pennsylvanian time. The Anadarko, Ardmore, and Arkoma Basins, and the Arbuckle Mountains, Seminole Arch, and Apishipa-Wet Mountain Uplift all developed in early Pennsylvanian (Morrowan and Atokan) time (Adler, 1971).

In summary, the second phase of movement on the Ste. Genevieve Fault Zone (in late Mississippian-early Pennsylvanian time) involved vertical uplift of the Ozark Dome relative to the Illinois Basin. The Devonian fracture zone was involved to a small degree, but the main Carboniferous fault developed just southwest of the Devonian faults. The Carboniferous fault is nearly vertical in the crystalline basement. Upward in the sedimentary section it curves away from the uplifted block, as a reverse fault, and it dissipates into a monocline. Other nearby faults and folds were developing at the same time, and some reflect the same tectonic style.

The mechanisms involved in the uplift of the northeast Ozarks are a matter for speculation. Let us consider the Ouachita geosyncline. The floor of this trough sank 30,000 feet (9000 m) or more and accepted an enormous volume of Chesterian, Morrowan, and Atokan sediments. This mass, in conjunction with subsidence, pulled the southern edge of the Ozark platform downward. The northern edge of the Ozark plate could have rocked upward in partial compensation. All we need assume is that the plate was rigid enough to rock rather than bend. The southeastern side followed that ancient zone of weakness, the Reelfoot Rift. Perhaps the Ozark platform rocked down to the Ouachita trough, up along the Ste. Genevieve Fault Zone, and "scissored" along the Reelfoot Rift (fig. 30).

Relationship of Ste. Genevieve Fault Zone to Reelfoot Rift

The primary goal of this study has been to assess the potential for earthquakes within the Ste. Genevieve Fault Zone. Although current seismic activity involving the New Madrid Seismic Zone is evidently caused by reactivation of faults in the Reelfoot Rift, we must determine whether the

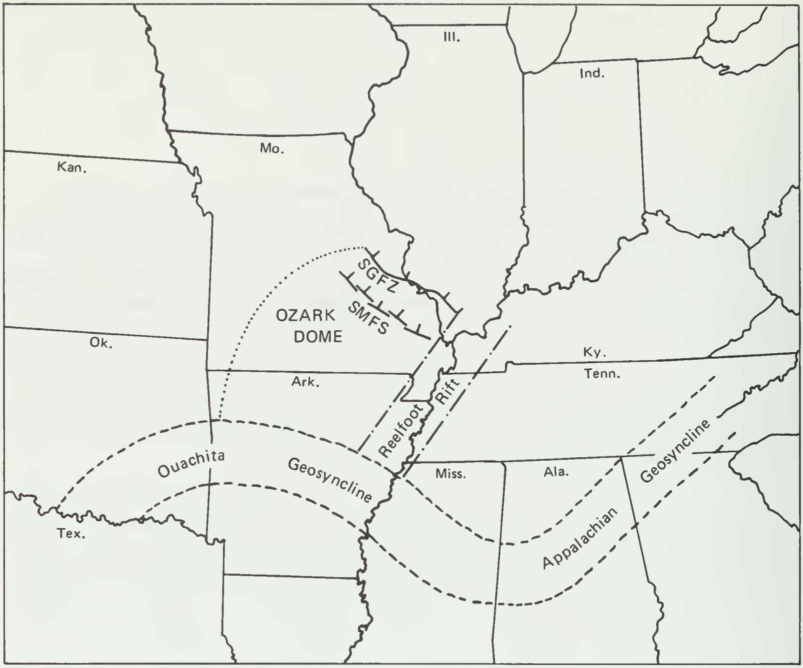


Figure 30
Schematic diagram illustrating the possible relationship between subsidence of the Ouachita Geosyncline and uplift of the northeastern margin of the Ozark Dome in late Mississippian-early Pennsylvanian time. The Ozark Dome may have acted as a rigid block, tilting downward into the Ouachita Geosyncline on the southwest and rising on the northeast, thus producing the Ste. Genevieve Fault Zone (SGFZ) and perhaps also the Simms Mountain Fault System (SMFZ).

Reelfoot Rift and the Ste. Genevieve Fault Zone are connected. Is the Ste. Genevieve Fault Zone, as Braile et al. (1982) suggested, a "northwest arm" of the Reelfoot Rift?

The Reelfoot Rift and Ste. Genevieve Fault Zone clearly did not originate together. The rift is a late Precambrian or early Cambrian structure; whereas the fault zone did not exist prior to Devonian time, some 100 million years later.

No arm of the original rift extended northwestward into the Ozarks. Cambrian through Devonian rocks on both sides of the fault zone represent platform or shelf-margin facies. There are no big grabens, no pre-Lamotte rocks, and no overthickened sedimentary sequences in the region. Faults that cut Precambrian and Cambrian rocks in the Ozarks have small (<1000 ft [300 m]) displacement, and are upthrust or small strike-slip faults (Tikrity, 1968; Gibbons, 1974). These fracture zones do not extend into the Mississippi Embayment.

It is true that the Precambrian igneous rocks of the St. Francois terrane exhibit a vague northwestward structural grain (Kisvarsanyi, 1981). This may be partially reflected in the geophysical surveys that have led to postulation of a "northwest arm." However, the St. Francois terrane is 1200 to 1500 million years old. It formed as long before the Reelfoot Rift, as the rift formed before the present.

It might suggest that the diabasic intrusions in the St. Francois Mountains are related to the opening of the Reelfoot Rift. The intrusions are known only to be somewhat younger than other Precambrian rocks, and older than Lamotte Sandstone. They might be the same age as the rift--or they might be several hundred million years older. Furthermore, they do not trend northwestward, as would be expected if they accompanied rifting. The dikes show strongly preferred bimodal orientations of N 5° W and N 75° W (Gibbons, 1974).

The Devonian portion of the Ste. Genevieve Fault Zone does not extend toward the Mississippi Embayment. Rather, it runs eastward into Illinois and dies out.

Thus we look to Carboniferous time for a Reelfoot-Ste. Genevieve connection. One problem in proving a connection is that the northern end of the Reelfoot Rift is poorly defined. Not enough deep test holes have been drilled in southern Illinois, and the geophysical data are rather ambiguous. No buried Precambrian or early Cambrian faults or scarps can be defined. The only indication/evidence we can provide is that basement surface drops 15,000 feet (4500 m) or more from Missouri to Johnson County, Illinois, where one drill hole penetrated pre-Lamotte sediments.

The northwest side of the rift, as inferred by Hildenbrand et al. (1977) from gravity and magnetic data, strikes approximately N 45° E from northeastern Arkansas through the "bootheel" of Missouri and terminates near the southern tip of Illinois.

The Ste. Genevieve Fault Zone ends as a major surface fault in northern Union County, Illinois, but other elements of the structure continue. The monocline curves to a south-southeast heading and extends to the Mississippi Embayment. Parallel with the monocline are the Atwood and Delta Faults and the Harrison Creek Anticline. The faults have the east side downthrown, and the anticline has the east limb steeper than the west limb. Therefore, these structures all show the same sense of displacement as the monocline. Morever, the total magnitude of vertical displacement across these various structures is nearly as great as it is farther north, along the Rattlesnake Ferry Fault.

These facts show that the Rattlesnake Ferry monocline south of Bald Knob, the Harrison Creek Anticline, and the Atwood and Delta Faults should all be considered the surface expression of the southward extension of the Ste. Genevieve Fault Zone.

Some geologists have suggested that the Ste. Genevieve Fault Zone continues southeastward, instead of curving southward. Surface geology does not support this interpretation. The only surficial structures that have been

linked with the Ste. Genevieve are a series of small faults in T 12 S, R 1 W, Union County (fig. 2). These faults were mapped and described in the Carbondale Quadrangle by Lamar (1925) and extended into the Dongola Quadrangle by Weller and Krey (1939). They are normal faults, striking N 10° W, to N 45° W, with their east or northeast sides downthrown. Maximum throw is about 65 feet (20 m) in the Carbondale Quadrangle and may exceed 100 feet (30 m) in the Dongola Quadrangle; lower Chesterian rocks and Ste. Genevieve Limestone are affected. Satterfield (1965) could not trace these faults into the Cobden Quadrangle.

Lamar's structure-contour map shows that in the faulted area the strata have an overall inclination of about 1 in 25, or 2 1/2°, toward the northeast. North of the faults the dip changes to north-northeast, and is less than 1°. The faulted area, therefore, roughly marks the northeastward boundary between monoclinal dips in the Ste. Genevieve Fault Zone, and regional, homoclinal dips toward the center of the Illinois Basin.

These little faults may be tension-relief features associated with the mild monoclinal folding. But they are too small and discontinuous to represent the main line of the Ste. Genevieve Fault Zone. That is located father west, where faults are larger and dips steeper.

Geophysical data tend to support our theory. A large gravity high marks the upthrown block of the Rattlesnake Ferry Fault. The gravity gradient bends and decreases south of Bald Knob, where surface faulting dies out. The gradient increases again in Alexander County, Illinois, on the east side of the large gravity and magnetic high that Heigold (1976) and McGinnis et al. (1976) called a mafic intrusion. A southeastward alignment of gravity anomalies appears in western Kentucky, but does not trace to the Rattlesnake Ferry high in Illinois. Therefore, the supposition of Hildenbrand et al. (1977) that the Ste. Genevieve Fault Zone projects into Kentucky appears poorly backed by geophysical evidence. Postulation of an extension of the fault zone to Alexander County is simpler and more direct, especially in light of Coe's detailed gravity profies (fig. 26).

Hildenbrand et al. interpreted the series of intense gravity and magnetic highs, along both margins of the Reelfoot Rift, as mafic intrusions. The Alexander County high probably is another of the same, although Hildenbrand et al. did not describe it as such. Their magnetic survey did not reach into Illinois.

All the above findings indicate to us that the Ste. Genevieve Fault Zone strikes south-southeast from Bald Knob and merges with the Reelfoot Rift in eastern Alexander County.

The loss of strong surface and geophysical expression of the southern end of the Ste. Genevieve Fault Zone probably reflects much greater depth of the basement fracture zone. As the fault zone enters the Reelfoot Rift, the Cambrian and Ordovician strata thicken by thousands of feet. The faulting, therefore, dissipated upward in the sedimentary succession, and the deformation spread over a much broader zone. Furthermore, at the junction, uplift may not have been confined to a single fault in the basement. The

Reelfoot Rift probably contained several subparallel faults that cut basement, and available to be reactiviated by Carboniferous uplift of the Ozark Dome.

Earlier in this report we postulated that subsidence and sedimentation in the Ouachita trough caused the northeast side of the Ozark platform to rock upward, creating the Carboniferous movement on the Ste. Genevieve Fault Zone. The Reelfoot Rift acted as the southeastern border of the tilting block. Faults in the rift acted in scissors fashion, as the southwest side of the Ozarks sank and the northeast side rose (fig. 30).

Modern Seismicity and Stress Field

• Seismicity

The pattern of earthquakes in the central Mississippi Valley has been well defined through study of historic records and modern seismograms. The greatest frequency of quakes, and nearly all the large ones (magnitude 6.0 or greater), occur along the narrow, linear New Madrid Seismic Zone (fig. 31). The seismic zone runs northeastward from northeastern Arkansas to the southern tip of Illinois, roughly following the western boundary of the Reelfoot Rift. Many smaller tremors occur outside the New Madrid Seismic Zone within a radius of 200 miles (320 km) or so from New Madrid.

In this region, a dense network of seismographic stations has recently been installed to facilitate more accurate plotting of earthquakes. Figure 31 is a map from Herrmann (1984) showing epicenters of earthquakes registered by the network from 1976 to 1982. Several interesting details stand out in this figure. The New Madrid Seismic Zone is seen to comprise two long northeast-trending segments, offset near their middle by a short, northwest-trending zone of earthquakes. Several clusters of epicenters seem to define a second northeast-striking belt, northwest of the New Madrid Seismic Zone in Arkansas and southern Missouri. Most interesting from our viewpoint is a vaguely defined belt of epicenters running from southernmost Illinois northwestward toward St. Louis. This belt approximately parallels the Ste. Genevieve Fault Zone.

Before concluding that the fault zone is active, we should examine the evidence relating to recent movement on the faults, and consider the tectonic mechanism that is producing the quakes.

Evidence of recent movement. No geologic or seismologic evidence has directly indicated that the Ste. Genevieve Fault Zone, or any portion thereof, is seismically active. No examples of deformed Quaternary sediments have been found. No raised or sunken areas, fault scarps, offset terraces, sand blows, or related features have been detected. In contrast, such structures are quite apparent in the alluvial deposits near New Madrid, Missouri. Some date from the great quakes of 1811-12, while others obviously are older.

Admittedly, deformational features in Quaternary deposits are commonly subtle and easy to overlook. Having no idea where to begin looking, we did not launch a full-scale search for Quaternary deformation. None of the many

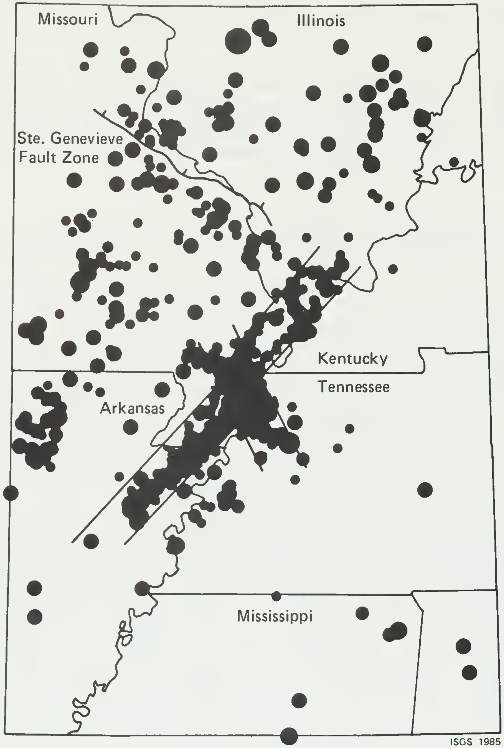


Figure 31
Epicenters of earthquakes in central Mississippi Valley from July 1, 1974 through September 30, 1984. Size of circle indicates relative magnitude, the largest being in the range of 4 to 5 on the Richter scale. A tremendous concentration of epicenters in the New Madrid Seismic Zone is apparent. Note the weak alignment of earthquakes along the Ste. Genevieve Fault Zone (from Herrmann, 1984).

geologists who have worked in the area have reported any suspicious features. On the other hand, Russ (1984) has looked for but found no suggestion of offset on stream traces 17,000 to 19,000 years old along the fault zone in Missouri.

On a larger time scale, Eocene (?) sediments straddling the fault zone in Illinois apparently have undergone little or no relative uplift since they were deposited. Whether they have experienced strike-slip movement cannot be answered.

No recorded earthquakes near the Ste. Genevieve Fault Zone can be attributed to movement on individual faults. Many epicenters are located away from any known or mapped structures.

In conclusion, we feel fairly safe stating that the Ste. Genevieve Fault Zone has not undergone catastrophic New Madrid-style earthquakes during the late Quaternary. We cannot, however, rule out less violent tremors, especially those that do not rupture surficial sediments.

Modern stress field. Data from a variety of sources consistently show that the northeastern United States is subject to a contemporary tectonic stress field. The principal compressive stress in this field is horizontal and oriented east-west to northeast-southwest (Sbar and Sykes, 1973; Zoback and Zoback, 1980).

Nelson and Lumm (1984) summarized evidence for stress in southern Illinois. Horizontal compression oriented east-northeast to east-west is indicated by focal mechanisms of earthquakes, a hydrofracturing experiment, in situ stress measurements in coal mines, and patterns of ground failure in underground mines. North-trending thrust faults of small displacement have been observed in many coal mines, and are suspected to be products of the modern stress regime.

Two focal analyses of earthquakes and one result of an overcoring experiment are available for consideration with respect to the Ozark Dome region of Missouri. One quake occurred on October 21, 1965, near Centerville in Reynolds County just southwest of the Precambrian outcrop area. Focal analysis signified normal faulting with principal compression oriented N 87° W. The other quake, southwest of Fredericktown in Madison County, had the pressure axis oriented N 46° W (Herrmann, 1979). The overcoring experiment was conducted in a granite quarry at Graniteville, Iron County, and showed maximum compression to be 3,190 psi, oriented N 77° E; whereas minimum horizontal stress was 1,397 psi at N 13° W (Hooker and Johnson, 1969). Thus, two out of three measurements favor east-west compression.

Most focal mechanisms of earthquakes in the New Madrid Seismic Zone also are consistent with east-west compression (Herrmann, 1984).

Sbar and Sykes (1973) attributed the current stress field to drag of the eastern North American continental plate against the mantle, as the plate drifts westward away from the mid-Atlantic ridge.

The final question is whether any faults of the Ste. Genevieve Fault Zone are likely to be re-activated under the modern stress regime. Faults can slip if their orientation is correct with respect to the imposed stress. Figure 32 shows the theoretical orientations of faults that can form, or be re-activated, under horizontal east-west compression. Thrust faults that strike north-south and dip less than 45° are most likely to be re-activated under the modern stress regime. No such faults occur in the Ste. Genevieve Fault Zone.

Strike-slip motion can occur on vertical or steeply inclined fractures that strike approximately 30° to either side of the principal stress. Such faults are known as conjugate shears. In the case of east-west compression, northeast-striking fractures would undergo right-lateral shear, while northwest-striking faults would be left-lateral (fig. 32). Many segments of the Ste. Genevieve Fault Zone are composed of high-angle faults trending in a

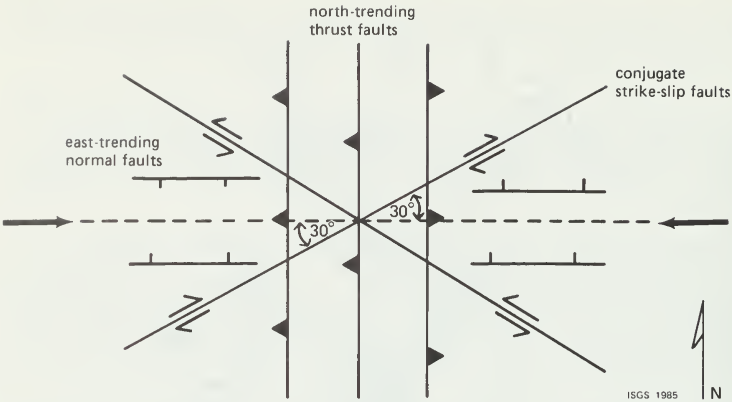


Figure 32
Diagram (map view) illustrating faults that may be formed or re-activated in a stress field with the principal compressive stress horizontal and oriented east-west.

northwestward or west-northwestward direction. These portions of the fault zone could experience left-lateral slip under today's stresses.

Olsson (1968) claimed that fracture patterns along the Rattlesnake Ferry Fault indicate left-lateral slip. We have rejected wrench faulting insofar as major Carboniferous movements of the fault zone are concerned. Some fractures along the fault zone, however, might be the product of modern, rather than of ancient stresses. Engelder (1982) and Foote (1982) have proposed that many joints or fractures in bedrock are recent features, produced as the confining pressure of overburden is relieved by uplift and erosion.

The third type of slippage that may occur under horizontal east-west compression is movement on east-striking normal faults. The Ste. Genevieve Fault Zone contains many normal faults that trend roughly east-west. The faults of Devonian age are especially noteworthy here. Also worth remembering is that the 1965 earthquake in Reynolds County, Missouri, involved slippage on an east-northeast trending normal fault.

Although we have no proof that the Ste. Genevieve Fault Zone is active, some faults of the zone may be capable of slipping under the modern stress regime. Both east-trending normal faulting and northwest-trending left-lateral faulting are possible. Whether such movement actually takes place depends upon many factors beyond the scope of our study. These factors include magnitude of stresses, local variations in stress field, strength of faulted versus unfaulted rock, and degree to which stress is released through mechanisms other than sudden movement on faults.

Catastrophic earthquakes on the Ste. Genevieve Fault Zone appear improbable, but moderate tremors are a possibility. The zone needs to be monitored by seismologists, and more information on in situ stress and strength of materials would be useful.

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